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Coiled Heat Exchanger with Small Radius Bent Tubes for Controlled Heat Treatment of High Viscosity Waxy Oil

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Abstract. The necessity of using the controlled heat treatment technology of oil instead of «hot pumping» is substantiated. A number of advantages of the "cold" transportation of oil are presented, as well as the main tasks that need to be solved for the successful usage of the above technology at the trunk oil pipelines. The main drawbacks of the heat exchanging equipment used at the heating and pumping stations of trunk pipelines for non-Newtonian solidifying waxy oils. Particular attention is paid to deposition and accumulation of wax in the flowing part of the equipment as well as the possibility of their safe quickly cleaning. The use of domestic twisted steel heat exchangers based on small radius bent tube is proposed. Constructive advantages of the proposed twisted heat exchangers are compared with the traditionally used equipment - shell-and-tube exchangers with horizontal and U-shaped arrangement of pipes, fully-welded plate heat exchangers, as well as finning air cooling units. For comparison, such technical and economic indicators as heat transfer rate, per surface area of heat exchange, complexity of operation, maintenance and repair, reliability and structural strength under cyclic loads in difficult thermobaric conditions are adopted. The issues of using twisted steel heat exchangers based on small radius bent tubes at trunk pipelines objects are considered taking into account successful experience of application in other industries.

1. Introduction

The effectiveness of chemical reagents widely used in oil production and pipeline transportation of high-viscosity solidifying waxy oils - depressant additives and paraffin inhibitors, as numerous studies have shown [11] is depends of the temperatures at which the oil undergoes treatment by reagents - the required level of preheating temperature should be higher than the melting point most of oil paraffins [10]. An important factor is also the rate of subsequent cooling of heated waxy oil [3]. The domestic experience of exploitation [4-9] on the "hot" main oil pipelines «Uzen-Atyrau-Samara» and «Usa-Ukhta-Yaroslavl» showed, widely used convection heating ovens and fully-welded plate heat exchangers do not provide the proper level of energy efficiency and reliability - the first one because of high fuel consumption, cost and maintenance costs, the last one - due to the complexity of their maintenance (cleaning from wax deposits) and low maintainability [9]. Another real significant disadvantage of fully-welded plate heat exchangers is the high hydraulic resistance in the flowing part, which increases during operation choking by deposits of waxy oil. The overwhelming share of the market for imported equipment in this segment is also a significant drawback.



2. Methods for improving the efficiency of heat exchangers

The heat exchange efficiency of apparatus depends most often on such factors as the flow of coolant (thermal transfer fluid), inlet temperature, degree of purity the heat exchange surfaces, and the ambient temperature. The first three parameters are usually constant for a certain operating mode, but the air temperature due to their daily average and seasonal fluctuations is the primary perturbing factor having a direct effect on the cooling process. The initial pumping temperature of oil significantly affects the hydraulic resistance of the pipeline. But the existing methods of calculating this dependence are complex and require many additional parameters. A.G. Vanchin proposed a new valuation technique based on the relative representation of regimes in relation to existing [2]. So it was determined that the listed parameters have a proportional relationship, which greatly simplifies the calculations.

In the course research made by A.U. Lipets [13], it was identified the main shortcomings of straight-tube heat exchangers:

- efficiency losses of the temperature flow in the single-staged cross current;
- expensiveness of aluminum pipes;
- thermal resistance at the interface of aluminum fins and steel pipes;
- small distance between the fins;
- ineffective sealing between a package of pipes and framing walls.

The most popular and simple way to improve the design of heat-exchanging tubes is to increase the area of the heat-dissipating surface of the pipes. In [10] the authors Sukhotsky A.B. and Kuntyshev V.B. studied the effect of fins height on the efficiency of heat exchange. Using the calculation-analytical method, a partial and generalized similarity equation for the heat transfer of tube bundles is obtained. V.B. Kuntyshev made a huge push to develop this industry. In her work [12] on the improvement of air cooling units, the author proposed a number of new designs for bimetallic finned pipes.

First, new types of pipe joints with finning were considered:

- pipes with twisted spiral fins, crimped into the wall of the supporting tube;
- with smooth L-finishing;
- with KLM-finishing (the horizontal shelf of the spiral finning is pressed mechanically into the artificial relief made on the outer surface of the supporting tube).

Secondly, new designs of aluminum finning for increasing the area of heat exchange and flow turbulence are proposed. In [11], V.B. Kuntyshev experimentally investigated the effect on the thermal and aerodynamic characteristics of the ratio of the intervals between the edges of a bimetallic pipe with rolled aluminum finning and their heights.

In [1], S.V. Alimov, O.L. Miatov and V.A. Lifanov investigates such methods of increasing heat transfer as the use of notches on the rolling aluminum finning, while comparing the efficiency of the heat exchangers with the upper and lower position of the fans. V.B. Kuntyshev [12] investigated the aerodynamic resistance of equilateral bundles of tubes with spiral aluminum finning, researching the pressure losses of the flow during transverse passage through six chess four-row bundles of bimetallic finned tubes. In the course of above experiment, the following results were obtained:

- it was noted a violation of the similarity theory, according to which the resistance curves of all six tube bundles must coincide;
- it was determined the dependence of the resistance curves on the pitch of the pipes;
- the greatest thermal efficiency was typical for bundles with a tight arrangement of finned tubes.

The review of the listed studies showed that the increase in heat transfer of finned straight-tube heat exchangers is associated with the complication of their design and maintenance, while the most significant drawback of the complicated form of the heat exchange surface is the fast contamination of the flow channels of the apparatus, and as a result - the growth of hydraulic resistance, the drop in heat transfer, productivity and efficiency heat exchanger.

There is not above lacks in fundamentally new designs of heat exchangers, not so long ago appeared on the domestic market, and which have no analogues in the world at present, the heat exchange surfaces of which represent twisted bundles of small radius bent tubes (SRBT) [17-20]. Such

a design of the heat exchange surface not only increases its area, but allows increasing the intensity of heat exchange due to high turbulence of the medium flow along the intertubular and in-tube flow channel spaces. The second advantage of SRBT is self-compensation of temperature deformations during rapid heating and cooling conditions. This type of heat exchanger is designed to work in any liquid and gaseous mediums. Another feature of twisted SRBT heat changers, important for heat treatment of high paraffinic oils, is the self-cleaning by to high turbulence of flows in both flow channel spaces, preventing deposition and accumulation of wax, as well as the possibility of safe rapid cleaning of the SRBT surfaces by thermal hydro shock. The variants of block-modular execution of heat exchangers makes it possible to optimally select the desired temperature regime and performance, and the high throughput of twisted pipes due to the creation of vortices and turbulization of flows eliminates the loss of productivity because of growth of hydraulic resistance . The option of vertical layout does not require a large area, it also facilitates access to internal surfaces for maintenance, allows for full air removal, draining and cleaning by own staff.



Figure 1. Sections of twisted coil (SRBT) in various options.

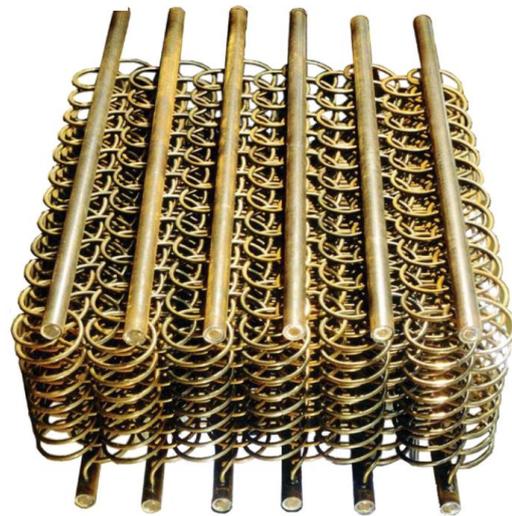


Figure 2. The heat battery of coiled sections of small radius bend tubes (SRBT) for air cooling units.

3. Advantages of coiled heat exchanger with small radius bent tubes

The increase in the efficiency per heat exchange surfaces by coils of small radius bent tubes (SRBT) in heat exchangers is caused by a much higher overall heat transfer coefficient. The principally new vertical arrangement of the heat exchange elements in combination with coiling by the calculated angle and with the corresponding diameter of the smooth pipe allows us to consider not only of the much more efficiency of the heat exchange surface compared with the standard finned tube and the typical horizontal arrangement of the last one, but also because of the high percentage of the influence of natural circulation on process of heat exchange, which determines the high energy efficiency of these apparatus, reducing the cost of electricity and maintenance (cleaning of finning). The area required of installation of air-cooling units based on SRBT is much smaller than the typical ones by more than 2-5 times, the heat exchange surface area is 8-12 times higher, as result the heat transfer coefficient is 2-8 times higher than the finned surfaces. It is also much more reliable, durable and maintainable than plate-type heat exchangers. The level of reliability of shell-and-tube heat exchangers based on SRBT is determined by design features, the absence or reduction to the minimum diameter of the tube boards, the usage full-strength welded joints allows talking about SRBT-type apparatus as equipment whit higher reliability and durability, especially when operating under conditions of cyclic or one-time changing loads, high temperatures and pressures, with a higher heat

transfer coefficient - 2-8 times more than in air-cooling units with finning and shell-and-tube heat exchangers - straight-tube types, both horizontal and U-shaped arrangement of pipes.



a



b

Figure 3. The option of installation of a compact modular design from sections based on SRBT in a cylindrical heat exchanger.

Figure 4. Increased resistance of devices based on SRBT to high temperature loads and deformations (a - straight-tube type, b - SRBT type).

Experience in the operation of air cooling units based on SRBT in exhaust systems with a temperature of up to 600 °C, in shell-and-tube heat exchangers with aggressive nitric gases, as well as their property of safe effective self-cleaning by hydro shock, allows to prove about their obvious and unconditional advantages in comparison with typical used finned tubular units of horizontal execution. Practical results of SRBT usage in the air cooling units for the lubricants production on refinery are shown in Table 1.

From Table 1 it is clear, when units based on SRBT in operation, the heat transfer is increasing, moreover, even with the fan switched off, only on natural convection, the efficiency of the SRBT air cooling units is many times higher than the straight-tube apparatuses of the AVG and AVZ types with a horizontal arrangement of tubes with finning because of maintaining the vortex flow of cooling air, which allows the heat transfer fluid to cool down to the ambient temperature even in the hot summer season (no more than 3-5 °C higher than the air temperature).

The above high efficiency indices of air cooling units based on SRBT, taking into account the option of their vertical arrangement, significantly reducing the area of site required, in addition to frequency-controlled fan drives, could allow smooth control and adjustment of the cooling rate of waxy oils at a given pace during their heat treatment, or in cases of pumping the too hot oil from the

fields. Moreover, in the second case, when the hot high-paraffin oil comes from the fields, it is possible to cool it at the required rate in the flow by air cooling units based on SRBT, and get a heat treatment effect that will significantly reduce the amount of oil waxy deposits in the tanks by reducing the temperature gradient and equaling of temperatures between the hot oil and cold metallic surfaces.

Table 1. The results of comparison of the actual operation of typical air cooling units (AVO and AVG types) with heat exchangers based on SRBT design.

Air cooling units	Total area of heat transfer surfaces m^2	on / off	Temperature			Thermal load Gcal / h	Thermal load per unit area Gcal / $m^2 \cdot h$	
			inlet	outlet $^{\circ}C$	Δ			
Regime № 1 – all units in operation								
AVO-1, AVG-14	1870	on	140	110	30	0,960	513	
AVO-1, AVG-14	1870	on	110	74	34	1,075	575	
AVO-2a (SRBT)	330	on	74	55	21	0,533	1615	
Regime № 2 – the only one SRBT-type unit in operation								
AVO-1, AVG-14	1870	off	140	134	6	0,197	105	
AVO-1, AVG-14	1870	off	134	130	4	0,130	70	
AVO-2a (SRBT)	330	on	130	90	40	1,241	3761	
Regime № – typical units in operation, SRBT-type unit is switched off								
AVO-1, AVG-14	1870	on	140	110	30	0,960	513	
AVO-1, AVG-14	1870	on	110	76	34	1,017	544	
AVO-2a (SRBT)	330	off	76	70	6	0,172	521	
			– the heat exchanger fan is on					
			– the heat exchanger fan is off					

4. Conclusion

Thus, the advantages of heat exchangers based on SRBT prior to typical straight-tube-and-shell heat exchangers and air cooling units with horizontal pipes arrangement, even with intensive finning, further complication of which leads to an increase in hydrodynamic resistance, drop in system performance, complication of maintenance and repair, inadmissible temperature deformations. In the case of plate heat exchangers, in spite of their higher specific heat output, their non-maintainability, high hydraulic resistance, high purchase price and operation costs lead to drop of system reliability and increasing the cost price of thermal energy. Table 2 presents a comparative analysis of the main operational parameters of plate heat exchangers and ones based on SRBT design on the example of cooling and condensation of water vapor by heating the water circuit.

Based on the results of the above comparison, it is obvious that coiled heat exchangers based on SRBT with similarly high thermal efficiency are more reliable in conditions of cyclic high-temperature loads, aggressive and inhomogeneous media than all-welded plate ones, but in comparison with the latter they have better mass-dimensional characteristics and technical and economic indicators, both in terms of the purchase price of equipment, as well as maintenance and repair costs.

Table 2. The results of comparison of the operational performance of plate heat exchangers and ones based on SRBT at the same equal heat output of 71,660 kW.

Comparison indicators		SRBT-design type	all-welded plate type	Comparison results
Dimensions	mm	Ø2200 x 2800 x 6000	Ø1600 x 3600 x 2500	The vertical layout of the SRBT type units requires a smaller site area
Weight	kg	17 700	19 129	SRBT type has less weight
Design	-	modular-collector / welded	all-welded / welded pack of round plates	The absence of access to the flowing channel part in all-welded plate type units
Layout	-	vertical	horizontal горизонтальное	All-welded plate type units requires more area site
Material	-	Stainless steel / carbon steel	Stainless steel / carbon steel	Pitting corrosion of stainless plates on all-welded plate heat exchangers
Heat transfer surface	m ²	824	1371	Specific heat efficiency of SRBT is 1,5 times higher
Reliability under cyclic loads by temperature and pressure	-	Self-compensation of temperature expansion and pressure drop by SRBT coils	The welded plate package is under cycling stress - deformation and rupture of welded joints	The reliability of SRBT design is more times higher
Emptying	-	Vertical arrangement of coils allows fast removal of the medium (liquid or gas)	A welded pack of plates makes it difficult to quickly and completely drain the medium	operation and maintenance of SRBT designed units is simpler and cheaper
Intensity of sedimentation and accumulation of deposits in flowing channels parts	-	The absence of stagnant zones and the swirling of the flow minimizes deposits	The process of deposition proceeds according to the standard scheme - overgrowing of plates and as result is loss of heat efficiency, drop of throughput capacity	The between-repair intervals of the units based on SRBT are longer, the operating costs are lower
Limitation on the operation temperature and pressure conditions	-	No (operating temperature up to 800 °C, pressure over 200 kgf / cm ²)	Yes (temperature limit up to 600 °C, pressure up to 100 kgf / cm ²)	the nomenclature series and the application area of the SRBT heat exchangers are much higher

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