ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XIII [2015] – Fascicule 2 [May]
ISSN: 1584– 2665 [print]; ISSN: 1584– 2673 [online]
a free– access multidisciplinary publication of the Faculty of Engineering Hunedoara

[1.] Tibor VARGA, [2.] Zoltán SIMÉNFALVI, [3.] Gábor SZEPESI

INFLUENCE OF VOTATOR'S CONSTRUCTION ON INTERNAL FLOW THROUGH SSHE (SCRAPED SURFACE HEAT EXCHANGER) AND THEIR USAGE FOR HIGH VISCOUS AND NON– NEWTONIAN PROCESS APPLICATIONS

[1– 3.] University of Miskolc, Institute of Energy and Chemical Machinery, Department of Chemical Machinery, Miskolc, HUNGARY

Abstract: Thermal processing (heating, cooling) of high viscous, non– Newtonian and in most of the case sensitive products in chemical, food and processing industry belongs to one of the base operation. Because of intensive presence of fouling and low heat transfer rates at thermal treating of these products, the only effective solution (taken into the consideration the continuous processing) are reached by usage of scraped surface heat exchangers– SSHE, with wide range of construction of votators. The detailed construction of votators has a major impact on internal flow of thermally processed products through SSHE. This mean, the total heat transfer efficiency is heavily influenced by their construction.
Keywords: Scraped surface heat exchanger, non– Newtonian fluids, CFD, Velocity profile

1. INTRODUCTION
Nowadays, thermal processing (heating, cooling) of high viscous, non– Newtonian products in chemical, food and consumption industry (e.g. caramel, puddings, chocolate, cheese, deboned meat, oils, glues, resins, printing ink etc.) is one of the most important technological process. Thermal processing of these products were managed first by batch processing (stirred vessels) but with request of considerable higher quantity and keeping the desired quality of treated products the scraped surface heat exchangers (SSHE) were developed. In principle the scrapers are used to keep clean the heat transfer tube from fouling and permanently remove and mix with main flow the treated products. There is a wide range of votator's construction, based on the numerous theoretical and practical scientific works. In general horizontal SSHEs are tube type, where inside the votator a shaft rotates within a tube. On the shaft are fixed scraper blades and possible rectifiers. The product passes through an annulus present between the shaft and heat transfer tube. The typical solution for shaft is the concentric location with heat transfer tube, but there are executions with eccentric location of shaft or with oval heat transfer tube. The last two executions are for viscous, extremely viscous or sticky products where we repress the mass rotation, channelling effect and reduce the influence from mechanical heat load.

2. THEORETICAL APPROACH
In general products, fluids processed in chemical, food and consumption industry can be categorised into two major groups. Fluids, for which the relation between shear stress τ_{xy} and shear rate $\dot{\gamma}$ is linear with intercept point in zero we call Newtonian fluids ($\tau_{xy} = -\mu\dot{\gamma}$) and those having the realition as $\tau_{xy} = -\eta\dot{\gamma}$, where generalised apparent viscosity $\eta = f(\tau_{xy,}\dot{\gamma})$ we call non– Newtonian fluids. For relation of η were explored a numerous empirical equations, like Eyringomn, Ellison, Reniner modelsetc. When in addition $\eta = f(t)$, we say fluids thixotropic or reopectic. Other thermodynamical properties υ, ρ, β, λ, c_p are pressure and temperature dependent as well.

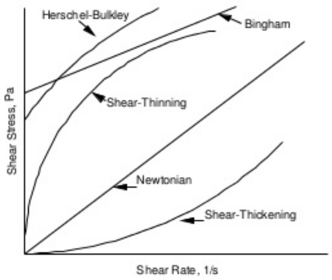


Figure 1. a – Typical time independent fluid curves

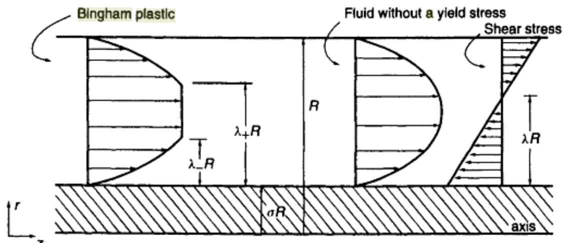


Figure 1. b– Schematics of velocity profiles for Bingham plastic and power– law fluids in a concentric annulus

In general the internal flow through horizontal SSHEs for high viscous, non– Newtonian fluids is characterized by axial laminar flow, where often the treated product can flow through the heat exchanger close to shaft without proper radial mixing. This lead to the lower efficiency of heat transfer or even the reduced quality of some sensitive products. To avoid above mentioned, the flow should be directional with usage of possible rectifiers or by scraper's design and position. The good radial mixing is a base for proper heat transfer process.

On the other hand, there are still more of detailed points of view which need to be considered at design of votators, e.g. the undesired back mixing effect, local swirling where temperature drop can occur, the distance of a tip of scrapers from heat transfer tube. Further, the less pressure loss due to the votator's construction is preferable.

3. CONSTRUCTION AND NUMERICAL MODEL OF NEW VOTATOR SOLUTIONS

As mentioned in a chapter2 a proper construction of votator should fulfil a series of requests. Based on this a new type of votator's construction is designed (shaft with scrapers and rectifiers), see Figure 2. These constructions expected to solve the mentioned troubles at flow through horizontal SSHEs (hereby presented only 3 new design of them). The construction STUs is a votator where on the shaft are located scrapers and rectifiers in two row and 4 sections rotated 90 deg. The axial mixing is expected intensive, but at very high viscous products the pressure drop and mechanical load on scrapers should be checked for given products (e.g. deboned meat). For other two types as oval shaft and shaft typ2 shape is for very high viscous products. The radial mixing expected good and pressure loss (interesting because of energy consumption) on reasonable level. The flow characteristic of new design of votators are checked by numerical analyses. For detailed valuation a huge amount of numerical analyses requested. Hereby shown only a part of them. Based on the first analyses, the design of votators can be adjusted if this will be required. For the mentioned analyses a simplified numerical model is used as a first approach under isothermal conditions. The simplified numerical model is the model which represent the area between the shaft and heat transfer tube. An extra length is added on the outlet side because of know definitions of the tool. The length of the heat exchanger for numerical model is L=1 m and the additional stabilisation part has L_{extra}=0.3 m. The outer, jacket diameter is D=0.0988/0.1229 m and the shaft diameter is d=0.048/0.060 m. The Figure 2 shows the layout and the numbers of scrapers and rectifiers. Investigated results were the velocity profiles, flow pattern, pressure losses, local vortices, primary and secondary flow through the heat exchanger. Applied products: honey, chocolate cream, ketchup, apple purée, caramel, vegetable oils. The numerical model was splitted for rotary and stationary domains.

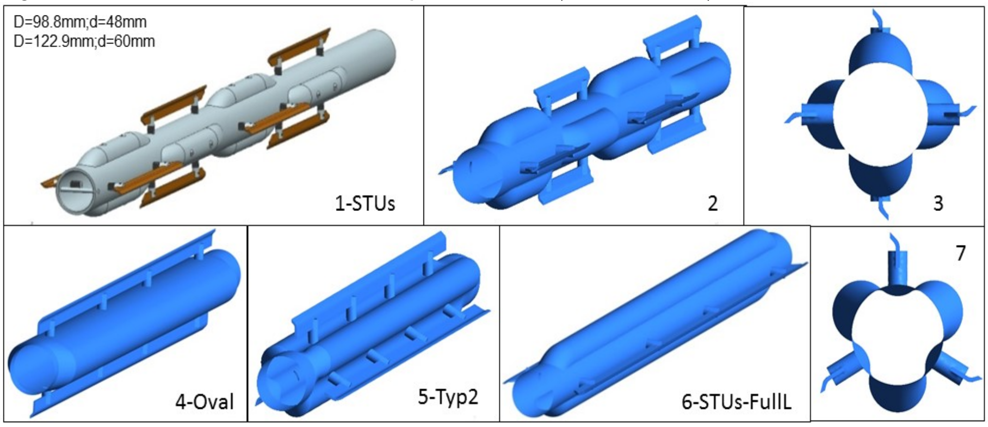


Figure 2 – New type of votators (shaft with scrapers and rectifiers); 1– construction of STUs type with located scrapers and rectifiers; 2,3 – the same from numerical model; 4– oval type of shaft with scrapers; 5,7 – type 2, shaft with same as on picture and 3 row of scrapers; 6– as STUs type, just with constant cross section.

As a next step the numerical analyses will be done for model with inlet and outlet cell included and under the process conditions (heating, cooling). Hereby shall be mentioned that a huge amount of numerical analyses were done under isothermal and process conditions with water as product, because an experimental plant was built with STUs type (and some different which not shown here) of votator to validate the results from numerical analyses.

4. RESULTS FROM NUMERICAL APPROACH

Hereby below are some results of analyses provided under isothermal conditions for votator types shown on Figure 3 and products as follows:

- Honey: $T_{ref}=20^oC, \rho=1345 kgm^{-3}$, $\eta=52.3 Pas$ (w=14%)
- Ketchup: $T_{ref}=25^oC, \rho=1075 kgm^{-3}, \eta=(\tau_0+k\gamma^n)/\gamma; \tau_0=32 Pa$, $k=18.7\ Pas^n$, $n=0.277$
- Chocolate cream: $T_{ref}=50^oC, \rho=895 kgm^{-3}, \eta=0.0278\ Pas$
- Apple purée: $T_{ref}=30^oC, \rho=1056 kgm^{-3}, \eta=k\gamma^n/\gamma$, $k=11.6\ Pas^n$, $n=0.34$

(Thixotropicbehaviour of ketchup was not taken into the account; free surface was excluded in numerical analyses)

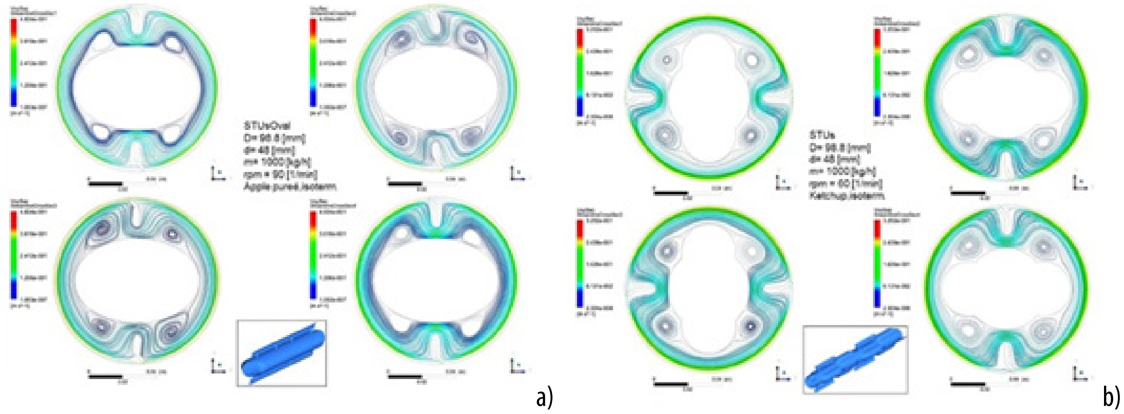


Figure 3 – Secondary flow in four cross sections for given product, votator and conditions as shown. Pressure drop through SSHE, a) Δp=5 312 Pa; b) Δp=4 993 Pa

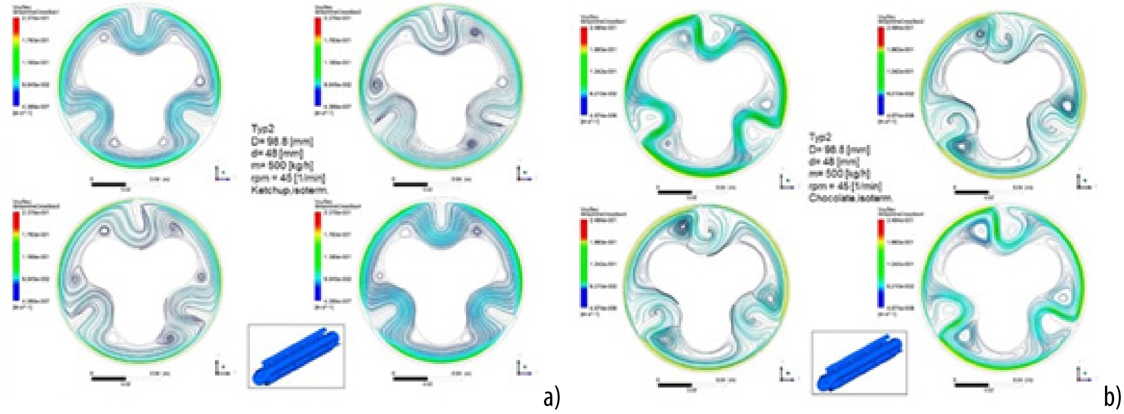


Figure 4 – Secondary flow in four cross sections for given product, votator and conditions as shown. Pressure drop through SSHE, a) Δp=5 352 Pa; b) Δp=475 Pa

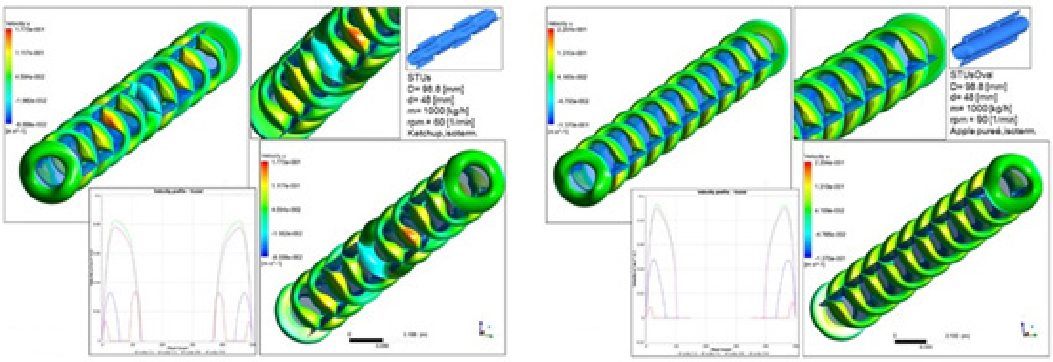


Figure 5 – Primary flow (axial flow) in 3D presentation and velocity profiles in several sections for given product, and conditions as shown

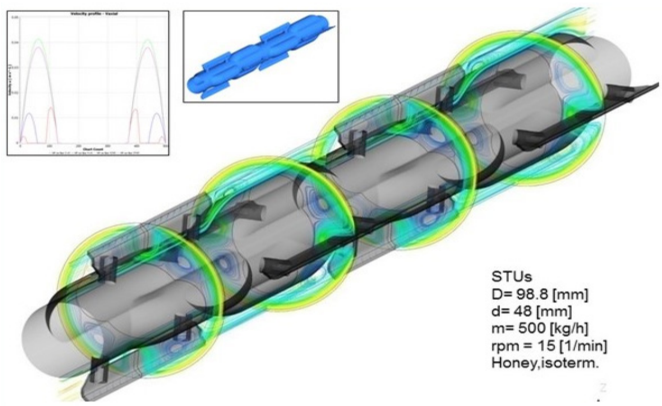


Figure 6 – Primary (axial) and secondary flow in some sections as shown and velocity profiles in several sections for given product,votator and conditions as shown. Pressure drop through SSHE, Δp=35.5 kPa

In a case of used product– ketchup and votator Type2 (see Figure 4) when m=500 kgh^{-1}, rpm=90 min^{-1} the pressure drop through SSHE is Δp=4103 Pa, when m=1000 kgh^{-1}, rpm=90 min^{-1} than Δp=5949 Pa.

5. CONCLUSION

As seen from a few shown results, pictures the radial mixing of the treated products are well assured. In all cases the treated product is scraped from the heat tube wall and properly mixed with the main axial flow. This is necessary for high heat transfer efficiency. There is a main stream in cross section which is well presented on the pictures of secondary flows. The mentioned fact, that product can flow through the horizontal SSHE close to the shaft without mixing with main axial flow is not present in any case for these type of votators. To find the best angular velocity of scrapers, shaft from the view of flow characteristic and heat transfer is a matter of more analyses with fine tune and check. Those results will be presented in future papers. The undesired axial back mixing should be check for all product and rotational velocity in a case of STUs type of votator, while at oval shaft and Typ2 shaft shape this can be neglected. With STUs type this effect can be reduced by using the same cross section design show on Figure 3 – 6 STUs– FullL (of course only in a case where the effect of back mixing is present).

Nomenclature

τ_{xy}	shear stress	[Pa]	c_p	specific heat capacity	[$Jkg^{-1}K^{-1}$]
τ_0	yield stress	[Pa]	T/T_{ref}	temperature, reference temperature	[K,ºC]
n	flow behaviour index	[–]	t	time	[s]
k	consistency coefficient	[Pas^n]	m	mass flow	[kgh^{-1}]
υ	kinematic viscosity	[m^2s^{-1}]	rpm	angular velocity	[min^{-1}]
η	dynamic viscosity, generalized viscosity	[Pas]	D	inner diameter of heat transfer tube	[m]
ρ	density	[kgm^{-3}]	d	outer diameter of shaft	[m]
β	thermal expansivity	[K^{-1}]	$v_{x,y,z}$	velocity components	[ms^{-1}]
λ	heat conductivity	[$Wm^{-2}k^{-1}$]			

Acknowledgement

This research was carried out as part of the TAMOP– 4.2.1.B– 10/2/KONV– 2010– 0001 project with support by the European Union, co–financed by the European Social Fund.

References

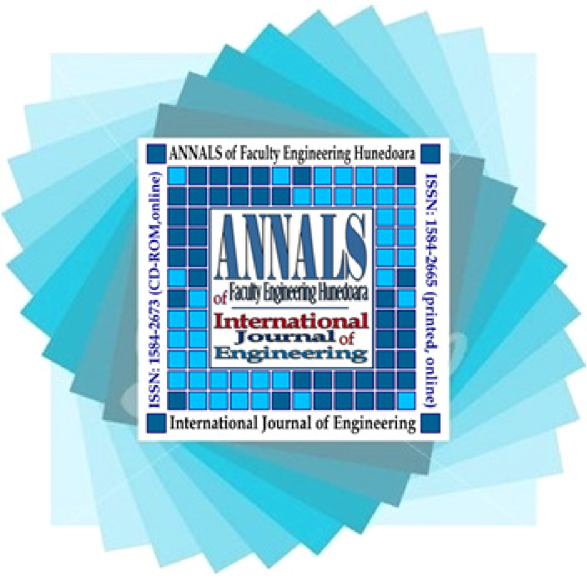
[1.] Härröd, M.; Flow patterns, mixing effects and heat transfer in scraped heat exchangers; Dept.of Food Science, Chalmers University of Technology, Sweden and SIK, The Sweden Institute for Food Research, Göteborg, 1988

[2.] J.A. Naser; Prediction of Newtonian & Non– Newtonian flow through concetric annulus with centerbody rotation

[3.] R.P. Chhabra, J.F. Richardson; Non– Newtonian Flow in the Process Industries, fundamental and engineering applications, Butterwoth– Heinemann, 1999

[4.] T. Varga, K. Jelemensky; Flow of high viscous and non– Newtonian fluids through scraped surface heat exchanger (numerical solution), 37th International Conference of SSCHE 2010, Tatranské Matliare, Slovakia, 2010

[5.] J. Šesták, J. Bukovský, M. Houška; Tepelné pochody– transportné a termodynamické dáta 4.vyd, CVUTv Prahe, 1998



ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering