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Influence of fluid structure upon the shape of RTD curve at a Sugar Crystallizer.

J. GRIFFITH[a], J.I. BORROTO[b] J.P. LECLERC[C]

[a]Department of Nuclear Techniques
Cuban Institute of Sugar Researches
Havana, Cuba

[b]Department of Radiochemistry
Institute of Applied Technologies and Sciences
Havana, Cuba

[C] Deputy Director Laboratory of Chemical Engineering Sciences of Nancy
(LSGC-CNRS-ENSIC)
Nancy Cedex France,

ABSTRACT.

The influence of fluid structure over the shape of the RTD curve at a pilot sugar crystallizer has been tested by the radiotracer method. For Newtonian pure molasses B sugar fluid the pattern flux was close to a perfect mixing cells with backmixing model with a back flow-rate ratio lower than one. In the case of the molasses B transformed to a non-Newtonian fluid the pattern flux approaches the same model but with extreme values of the back flow-rate ratio (higher than one). A direct relationship was founded between the back flow-rate ratio and the flow index of the tested fluids, showing that a special attention has to be pay during data processing of the RTD curves for no-Newtonian fluids.

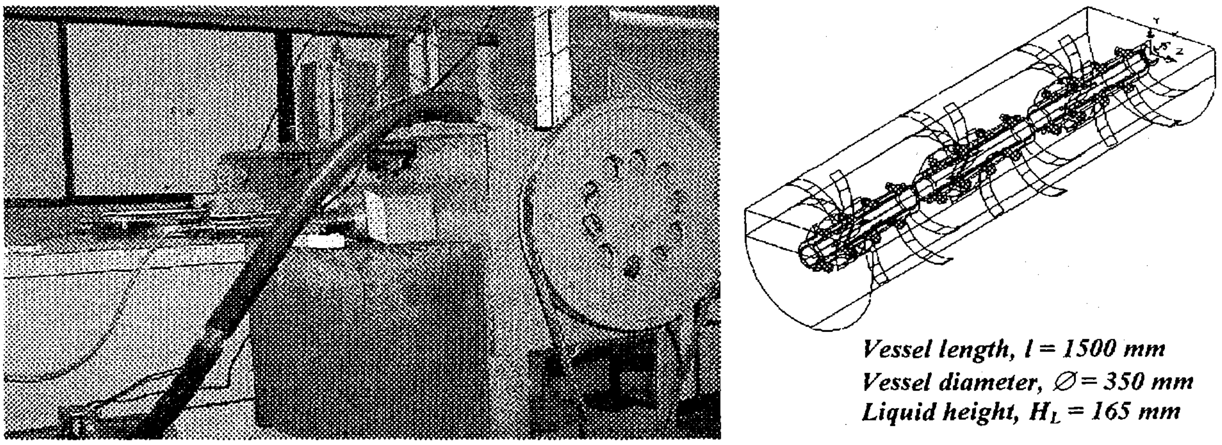
Introduction

The last step in the crystallization process at a raw sugar factory takes place at the so-called low-grade exhaustion crystallizer. Sugar crystallization is really a complicated process because involve two phases (crystals and the mother liquor commonly known as massecuite) that constantly are changing due crystal growth. The description of the hydrodynamic characteristics of the massecuite fluid that flows within this type of crystallizer using the tracer technique has been reported in several works /1-3/. During the last CRP, experiments have been conducted in the industrial crystallizer. The obtained results show that the presence of non-Newtonian fluid inside the crystallizer leads an unexpected deformation of the RTD curve. The approach initially reported by Griffith /4/ following the same procedure developed by Niemi in the case of non-constant flow-rate, by a normalization of the RTD by the apparent outlet viscosity to smooth the fluctuations and to obtain a RTD curve closer to the expected one, is still arguable and needs further validation. Although this empirical approach is debatable, these results showed clearly the effect of the non-Newtonian characteristic on the RTD measurement. Since such fluids are commonly used in the food industry, it is very important to go further in this type of research. Precisely taking in account this last statement, in the present work some preliminary results related to the influence of flow structure upon the shape of the RTD curve at a pilot sugar crystallizer are brought to analysis.

EXPERIMENTAL

Pilot crystallizer

A sketch of the pilot crystallizer and geometrical parameters of the mixing system investigated is shown in Figure 1. The unit was designed and constructed very close to the "Blanchard" type exhaustion crystallizer almost common in the majority of raw sugar factory in Cuba. It is a U horizontal half cylinder (*1200x350x270 mm*) divided in three compartments by two vertical baffles. The fluid passes from one compartment to other one by overflow. The impeller is composed by 30 curved blades along the shift (10 for each compartment) disposed with an angle 36° to avoid the formation of stagnant zones. In addition, it is equipped with a water jacket for temperature regulation.



Vessel length, $l = 1500$ mm
Vessel diameter, $\varnothing = 350$ mm
Liquid height, $H_L = 165$ mm

F.1. View and geometrical parameters of the pilot crystallizer.

The baffles were designed also to have a space without agitation for the installation of the viscometer spindle, conductivity cell and other measuring devices. However, after some preliminary test conducted with water, sugar syrups and molasses, it was shown that the installed baffles were an obstacle for the free movement of some part of the fluid entering into the unit and provoking backmixing effect. Then, the initial design of the crystallizer was modified and the installed baffles were removed.

Fluids

Different fluids covering a wide range of viscosities ($1{,}002 < \mu < 3{,}4\times10^5$ mPa· s) were used in tracer tests to obtain the RTD curves. The Newtonian fluids were water, mixture of glucose syrups with various water concentrations, and molasses B and C and the non-Newtonian fluids were molasses B with different proportions of 3% solution of Carboxyl Methyl Cellulose (CMC). The main rheological characteristics of the fluids are reported in Table 1.

TABLE 1. Fluid parameters

Fluids	Crystal content (%)	Brix (%)	Pol (%)	Purity (%)	Density (kg/m^3)	Flow index (n)	Consistency (mPa· s)
Newtonian fluids							
Water	–	–	–	–	998	0	1,002
Glucose syrup	–	69,5	–	–	1344	0,980	262
Molasses B	–	–	50,40	69,7	1316	0,958	918
Molasses C	–	89,5	33,0	36,9	1475	–	43952
Non-Newtonian fluids							
Fluid A*	–	54,7	29,3	53,0	–	0,788	359
Fluid B**	–	57,9	32,8	56,0	–	0,845	593

* Molasses B + 3% solution Carboxyl Methyl Cellulose (4:1 w/w)

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The apparent viscosity (consistency index) of these solutions has been measured with the Brookfield Programmable Rheometer using the properly spindle. The Newtonian flow behavior of these solutions was described by the following power law equation:

$\mu = K\gamma^{n-1}$

The relation between the shear stress and the shear rate is easily obtained by:

$\tau = K\gamma^{n}$

where,

μ; is the apparent viscosity of the fluid (Pa·s)

γ; is the shear rate (s^{-1}).

τ; is the shear stress (din/cm^2)

K; is the consistency (cP or Pa·s^n)

n; is the flow index (dimensionless). This is a measure of the extent of Newtonian behavior (n<1 non-Newtonian; n ≅ 1 Newtonian)

The calibration of Brookfield Programmable Rheometer was done using the standard fluid recommended by the suppliers that behaves itself as a typical Newtonian fluid (Glycerin) with a viscosity of 954 mPas at 25°C. The measurements show a good accuracy and reproducibility in the apparent viscosity (957± 10 mPas; Relative Error = 1.04%) and upon the Flow index (0.973 ± 0.0099; Relative Error = 1.02%)

Tracers

Taking in account that there is not any nuclear installation for the production of short-lived radioisotopes in Cuba, among the commercial radioisotope generators available, two of them ^{99}Mo/^{99m}Tc and ^{113}Sn/^{113m}In were chosen for this work.

Detection

Three collimated NaI(Tl) 1"×1" detectors coupled to ratemeters (*Miniken*, Australia) were used. Two of them were placed in fixed positions over the crystallizer or at its wall and the third at the outlet. Signals from each ratemeter were recorded continuously to a PC and the software D.T.S PRO was used for data treatment and modeling [5].

RESULTS

Tracer tests with Newtonian fluids

Tracer tests were performed with molasses B as standard for the comparison with non-Newtonian fluids. Several attempts were done to insure the correct response of the outlet detector in order to achieve the real DTR function of the system.

About 1,85 GBq (5 mCi) of ^{113m}In (5 ml of the eluted solution) thoroughly mixed with 5 g of molasses B was suddenly injected at the unit inlet. The rotation speed of the agitation system was fixed to 0,314 rad/s (3 rpm) and the volumetric flow was situated at 4,3 L/min. Samples were periodically drawn out at the outlet of the crystallizer and measured at the APTEC system composed by a well-shielded scintillation NaI(Tl) 2"×2" detector coupled to a multichannel analyzer.

In Figure 2, the RTD curves for the "on line" outlet detector D3 and the sampling method are shown. They are quite similar which demonstrated that the response of the outlet well-collimated shielded detector describes correctly the RTD function of the tested fluid within the crystallizer and therefore the pattern flux.

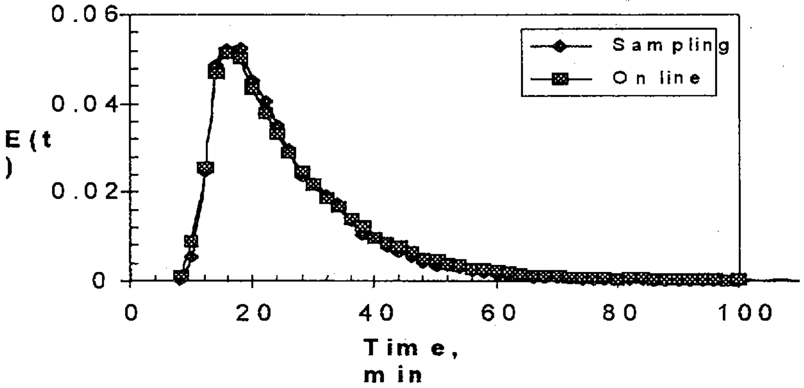
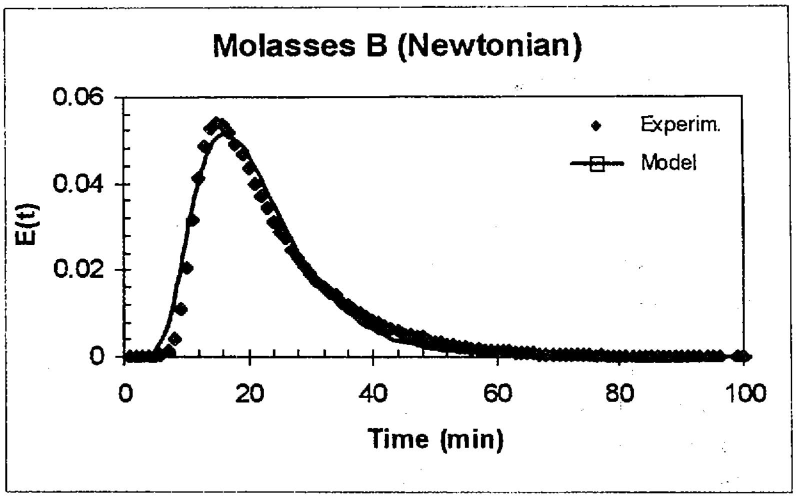


FIG.2. Comparison of RTD curve by "on line" and sampling methods (molasses B)

The first attempts to fit the tracer response curve to a model of perfect mixing cells in series, as it was achieved early in the previous tests performed before the redesign of the crystallizer, did not succeed. The only way to fit the response curve to a model with a physical meaning was assuming a model of perfect mixing cells with backmixing (PMCB) within the crystallizer (Figure 3).



Flow index	0.95
Flowrate Q	4.3
Tau	20.61
Volume	88.2
J	10
Alpha	0.7

Fig.3 Fitness of the RTD curve to PMCB model.(Fluid Molasses B)

Almost a similar picture show the response curve obtained by an also well collimated detector located lateral to the outlet of the pilot crystallizer which reinforce these preliminary results.

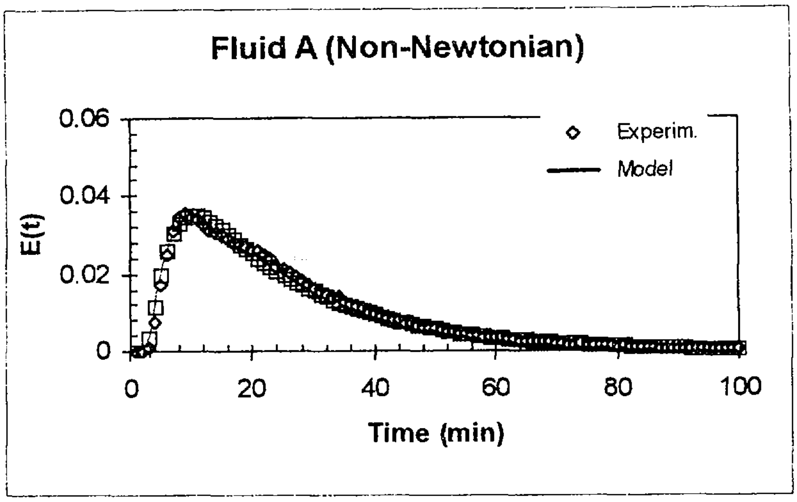
The relative high value of the back flow-rate ratio (alpha) seems to have relation with the fact that in the redesigned crystallizer measures are performed at the outlet of the unit where the fluid is forced to exit through a narrow gate and not by overflow. From our point of view, it seems logic that a part of the fluid has to recirculate or has to go to a backmixing process before leaving the crystallizer.

Tracer tests with non-Newtonian fluids

Following the approach described in [6], different proportion of a 3% solution of Carboxyl Methyl Cellulose (CMC) was added to the molasses B in order to achieve a non-Newtonian fluid (flow index less than 1). This procedure provoked the dilution of the original molasses B with the corresponding reduction of the apparent viscosity (consistency) and Brix. For these reason only two non-Newtonian fluids were prepared with the composition shown in Table 1.

Under similar conditions (, rpm, and temperature) as mentioned above for pure molasses B a preliminary test was performed employing the Fluid A. In order to validate once more the response of the detector, samples were drawn periodically. Again the RTD curves obtained by both methods are quite similar, and the experimental response curve fits to PMCB model (Figure 4):

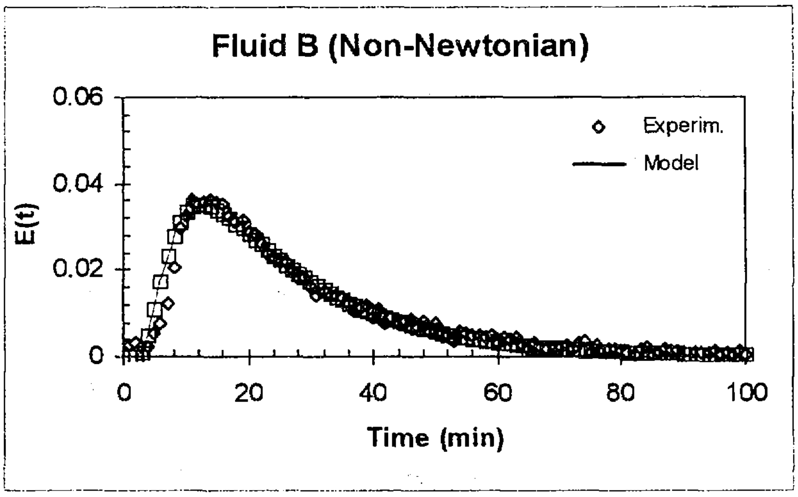
In order to compare this result with the Newtonian Molasses B fluid, in the fitting process to a PMCB model we fix the number of cells to the same values (j=10) and search for the value of the back flow-rate (alpha) that better adjust to the experimental RTD curve. In a first approximation these results were unexpected due that show a very markedly difference between the Newtonian and no Newtonian tested fluids upon the shape of the RTD curve.



Flow index	0.79
Flowrate Q	3,5
Tau	25.5
Volume	89.25
J	10
Alpha	6,2

Fig 4. Fitness of the RTD curve to a PMCB model (Fluid A)

Due that the great difference between these two categories of fluid was not only in the value of the flow index, but also upon the consistency, it was decided to carry out another test with the Fluid B, with composition intermediate between the two extreme fluids (Figure 5).



Flow index	0.85
Flowrate Q	3,5
Tau	25.5
Volume	89.25
J	10
Alpha	4

Fig.5 Fitness of the RTD curve to a PMCB model (Fluid B)

Again the pattern flux is close to the PMCB model, with a back flow-rate ratio value between the two extreme fluid.

With the aim to clear up this phenomenon, the RTD curves for molasses B (n = 0,952), Fluid A (n = 0,788) and Fluid B (n = 0,845) are plotted in the same graphic for comparison (Figure 6). Tables 2 resumes the parameters derived from these curves

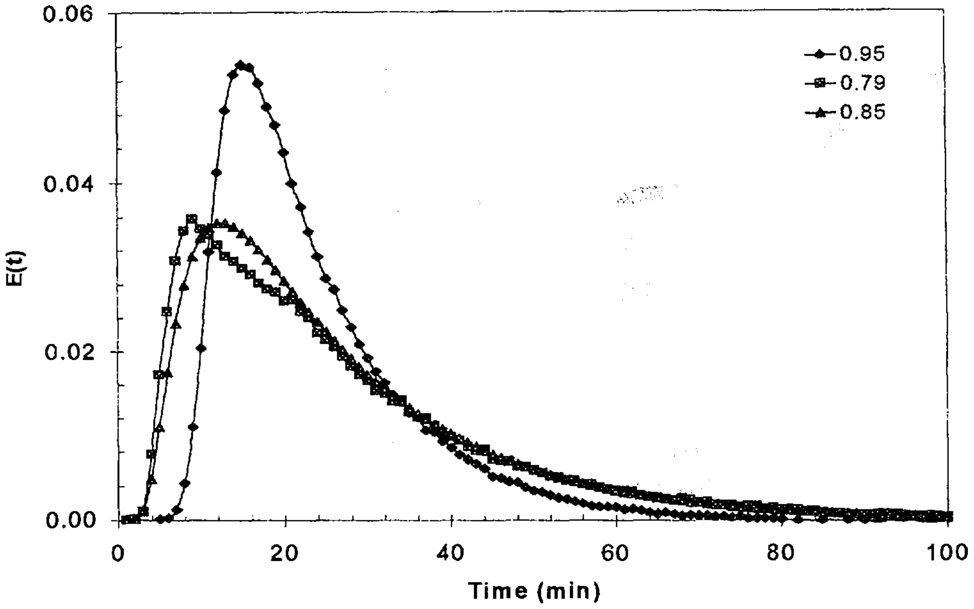


Fig.6 Influence of flow index n upon the shape of the RTD curve

Table 2. Test conditions and parameters of the RTD curves.

Fluid	Molasses B	Fluid A	Fluid B
Flow index	0.95	0.79	0.85
Flowrate Q	4.3	3.5	3.5
Tau	20.61	25.5	25.5
Volume	88.2	89.25	89.25
J	10	10	10
Alpha	0.7	6.2	4

These results indicate that with the diminishing of the flow index, and that is to say, when the fluid has more non-Newtonian character, the pattern flow comes more closer to a model with high values of back flow-rate or recirculation. In other words a high degree of mixing is taking lace within the facilities.

A very good correlation was found between the flow index and the back flow-rate ratio value (Figure 7).

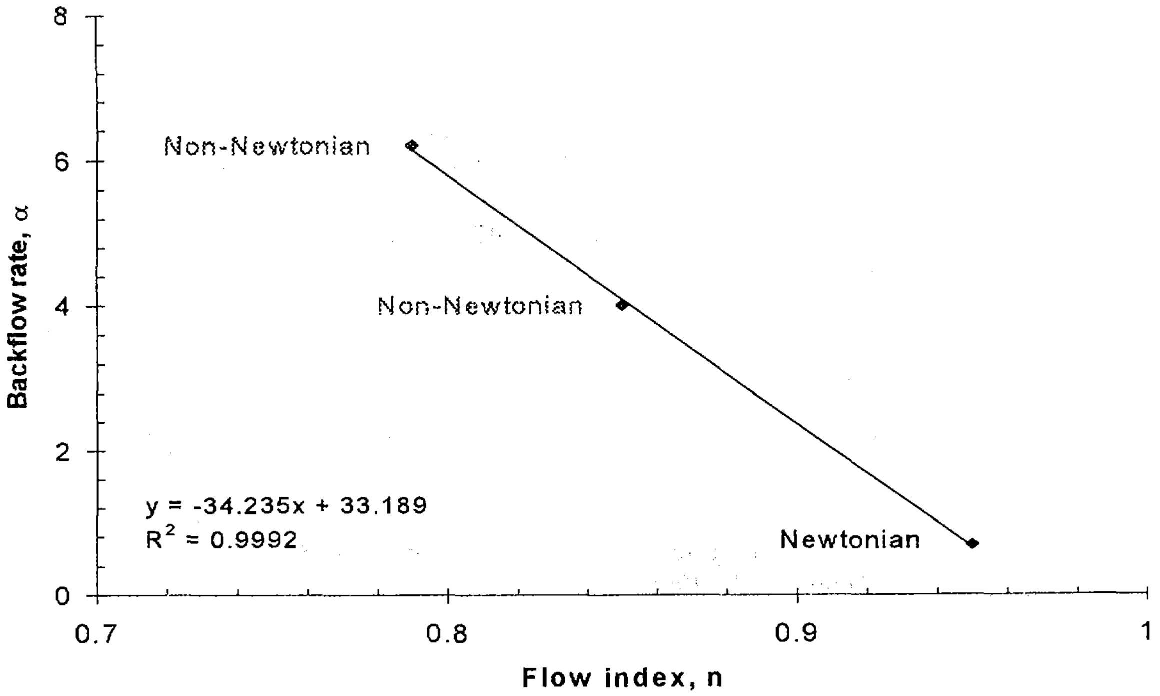


Fig.7 Correlation between the back flow- rate ratio and the Flow index.

Further test that could corroborate this markedly influence of the flow index on the hydraulic displacement of liquids needs to be carried out, taking in account that non-Newtonian tend to be the rule rather than the exception in the real world. These results represent a new challenge for the RTD specialist in the search of a numerical approach to consider the flow behavior of non-Newtonian fluids.

CONCLUSIONS

1. The fluid structure has a sharp influence upon the shape of the RTD curves. In the region of non-Newtonian fluid the hydraulic displacement in the pilot crystallizer approaches a Perfect Mixing Cell with backmixing model with extreme values of the back flow-rate value.

2. A straight correlation was founded between the back flow-rate ratio and the flow index, showing a dependence that must be taken in account for data processing and modeling of the experimental outlet curves in RTD determinations.

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