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## IMPACT OF PROCESSING CONDITIONS (FLOW REGIME, HEATING) ON RESIDENCE TIME DISTRIBUTION IN TUBULAR JOULE EFFECT HEATERS.

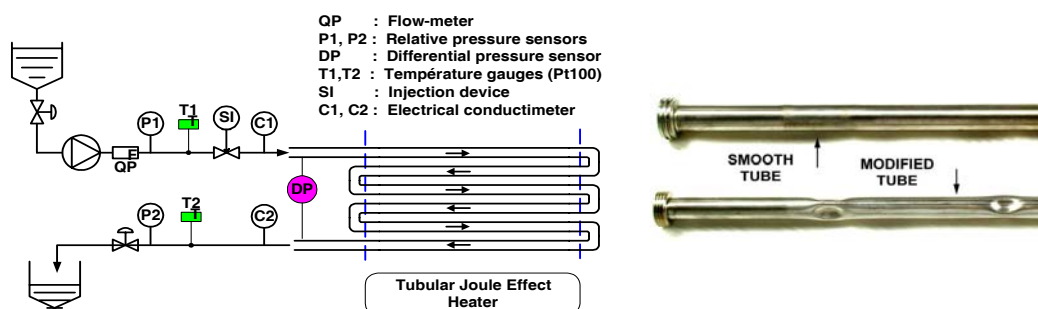
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**Abstract.** To improve treatment homogeneity in tubular Joule Effect Heater (JEH), geometric modifications could be used even in laminar regime inducing flow perturbation and mixing. As a response variable, RTD is an important parameter and it has been commonly used in determining the performances of industrial heat exchangers. RTD analyse provides information about the degree of mixing, cooking and shearing which play an important role in the final product quality. RTD are used for scale-up and improving equipment design. In this work, our objectives were (i) to investigate the impact of processing conditions (flow regime, heat power) on Residence Time Distribution (RTD) in industrial Joule Effect Heater (JEH), (ii) to propose a general reactor model including flow regime and heat power and (iii) to define a quantitative criteria of treatment homogeneity. The analysis demonstrates that (i) heat transfer and flow regime improve treatment homogeneity by increasing the plug flow contribution and reducing the value of reduced variance, (iii) the earliest transition from laminar to turbulent flow regimes due to temperature increase along the reactor induce a reduced variance and (iii) the proposed model enabled to predict RTD in JEH with an accurate degree of confidence.

**Keywords :** RTD, Joule Effect heater, food process, heat treatment.

### EXPERIMENTAL PROTOCOL

The experimental set-up (Figure 1) consisted of an agitated vessel (600l), a volumetric feed pump (Albin, MR 25I2-207548) and a tubular Joule effect heater. RTD were scrutinised in an industrial tubular exchanger JEH (Actini, 12 tubes and 11 junctions,  $\varnothing_{int/ext}= 18/20\text{mm}$ ,  $L=1400\text{mm}$ ) under heating power ( $0 < P < 13\text{kW}$ ) and three flow regimes ( $Re \approx 40$  to 4000 at JEH inlet). Modified tubes are made from smooth tubes; the geometrical modifications consist in three pinchings (length 25mm, width 13mm and depth 4mm) on a section with 120° angle between them. This motive is repeated along the heating length with a regular space (140mm) and an alternated angle (60°). Experimental measurements were: flow-rate, bulk and wall temperatures, electric conductivity, differential and relative pressure and electrical conductivity. All signals were electrically conditioned (module SCX-1) and collected using a data acquisition card (AT-MOI-16E-10) and a software driver Ni-DAQ. Measurements were saved on a PC (PC Pentium 200 MHz) with a specific software (Labview).



**Figure 1 : Experimental set-up and injection device (SI) - image of ST and MT.**

RTD experiments were conducted with water and sucrose solutions under a flowrate of 200l/h. An injection and detection device was developed to realise homogenous injections of tracer even in a laminar flow. NaCl was used as tracer for RTD.

### RESULTS AND DISCUSSION

We define  $x(t)$  and  $y(t)$ , experimental inlet and outlet normalised signals. The mathematical relation between  $x(t)$  and  $y(t)$  is described by Eq.1. This product of convolution can be replaced in Laplace domain by a simple product (Eq.2) and  $X(s)$ ,  $Y(s)$  and  $G(s)$  are the Laplace transforms of  $x(t)$ ,  $y(t)$  and  $E(t)$ . The analytical solution of  $E(t)$  was obtained from the

data analyse with DTS Progepi software. A systemic analyse based on simple models such as cascade of N continuous stirred tank reactors (CSTR) or a dispersed plug flow (DPF) are used for modelling RTD experiments. The DPF model was often found to yield the best agreement between numerical and experimental results. Furthermore, it has the advantage of requiring the estimation of only one parameter (Eq.3 and 4), the Peclet number ( $Pe$ ).

$$y(t) = \int_0^t E(u).x(t-u).du \quad \text{Eq.1} \quad \left. \begin{aligned} X(s) &= L(x(t)) \\ Y(s) &= L(y(t)) \end{aligned} \right\} G(s) = \frac{Y(s)}{X(s)} \Rightarrow E(t) = L^{-1}(G(s)) \quad \text{Eq 2}$$

$$E(t) = \frac{1}{2} \cdot \left( \frac{Pe}{\pi \cdot \tau \cdot t} \right)^{1/2} \cdot \exp\left( -\frac{Pe \cdot (\tau - t)^2}{4 \cdot \tau \cdot t} \right) \quad \text{Eq.3}$$

$$\beta^2 = \frac{\sigma^2}{t_s^2} = \frac{2}{Pe_L} \quad \text{Eq 4}$$

The DPF model (Eq.3) has been widely applied to describe the flow in a tube, and is the most frequently selected to simulate flow in holding tubes in aseptic processes. Peclet numbers,  $Pe$  were determined by curve fitting and minimizing the sum of squares of residuals (SSR) as reported in Table 1. If model is in agreement with experimental  $\beta^2$  showing the difference between ST and MT (Figure 1); the analysis of specific RTD curves were found to yield inconsistent and inaccurate results in our study. It means that a more complex and realistic model is required (e.g. cascade of a plug reactor,  $\tau_p$  in series with 2 CSTR,  $\tau_m$ ).

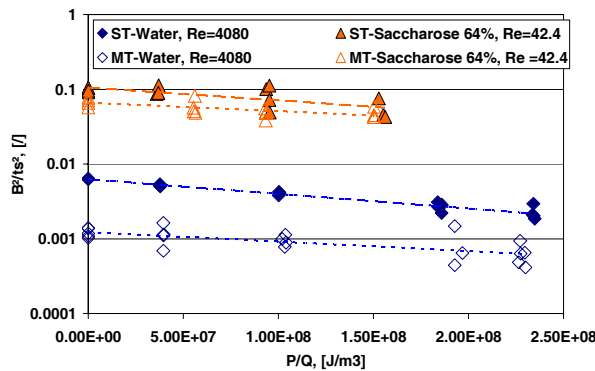


Figure 2: Experimental reduced variance,  $\beta^2$  versus  $Re$  and volume heat power,  $P/Q$ .

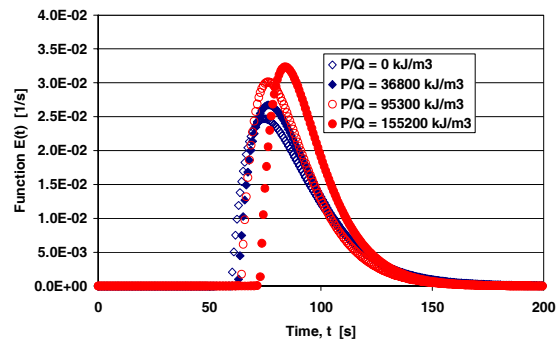


Figure 1: RTD curves,  $E(t)$  versus volume heat power,  $P/Q$ , ST,  $Re$ -Inlet=42.4.

|           | $Re$ -Inlet | $Re$ -Outlet | Power | $Pe$ -ST | $\tau$ | Power | $Pe$ -MT | $\tau$ |
|-----------|-------------|--------------|-------|----------|--------|-------|----------|--------|
|           | [/]         | [/]          | [kW]  | [/]      | [s]    | [kW]  | [/]      | [s]    |
| Laminar   | 42.4        | 42.6         | 0     | 64       | 81.3   | 0     | 70       | 77.8   |
|           |             | 82.6         | 2.03  | 66       | 81.0   | 3.13  | (56)     | 84.4   |
|           |             | 171          | 5.26  | 70       | 83.0   | 5.2   | 72       | 80.2   |
|           |             | 390          | 8.59  | 84       | 88.0   | 8.32  | 90       | 84.5   |
| Turbulent | 4080        | 4080         | 0     | 550      | 86.2   | 0     | 1224     | 84.7   |
|           |             | 4852         | 2.10  | 616      | 86.5   | 2.18  | 1339     | 86.1   |
|           |             | 6449         | 5.56  | 735      | 86.6   | 5.75  | 1488     | 84.2   |
|           |             | 32362        | 10.4  | 907      | 86.2   | 10.6  | 1712     | 85.6   |
|           |             | >35000       | 13.2  | 1180     | 85.9   | 12.64 | 2632     | 83.3   |

Table 1 : Peclet numbers issued from DPF model with ST and MT

## CONCLUSION

In conclusion, this work demonstrates that (i) heat transfer and flow regime improve treatment homogeneity by increasing the plug flow contribution and reducing the value of reduced variance, (iii) the earliest transition from laminar to turbulent flow regimes due to temperature increase along the reactor induce a reduced variance and (iii) the proposed model enabled to predict RTD in JEH with an accurate degree of confidence.