OBTURATING SURFACES IN THE JUNCTION OF TWO CANDU FUEL BUNDLES

Cezar DOCA[1], Constantin PĂUNOIU[2]

Rezumat. *La Institutul de Cercetări Nucleare Piteşti, a fost dezvoltat un produs software generalizat destinat proiectării fasciculelor de combustibil tip CANDU, respectiv calculării ariei suprafeţei obturatoare din joncţiunea a două astfel de fascicule combustibile, la rotaţii din grad în grad în domeniul [0º – 360º]. Programul calculează de asemenea toate căderile de presiune locale (la intrarea în fasciculul combustibil din amonte, la ieşirea din fasciculul combustibil din aval, în dreptul patinelor şi al distanţierilor, în zona joncţiunilor etc.), precum şi căderile de presiune distribuită şi totală pentru o coloană de 12 fascicule combustibile. Lucrarea prezintă rezultatele grafice obţinute pentru variaţia ariei suprafeţei obturatoare în cazul a 68 de tipuri de joncţiuni, la o rotaţie completă de 360º, din grad în grad.*

Abstract. *At the Institute for Nuclear Research Pitesti, Romania, it was developed a general software application used to design and calculate the aria of the obturating surface in the junction of two CANDU fuel bundles, for rotations, degree by degree, in the [0º – 360º] domain. The code also calculates all local (input, output, in spacers' zone, in junctions, etc.), distributed and total pressure drops for a fuel bundles string. The present paper expounds the graphical results representing the variations of the obturating surfaces for 68 types of junctions, at a [0º–360º] rotation, degree by degree.*

Keywords: CANDU Fuel; Obturating Surface

1. Introduction

At the Institute for Nuclear Research (ICN) Pitesti [1], Romania, it is developed an important theoretical and experimental activity to compare the hydraulic characteristics of various type of CANDU fuel bundles, such the pressure drop of the coolant agent (i.e. heavy water, D_2O) [2].

For a 12 fuel bundles string charged in the horizontal CANDU fuel channel, an important part of the total pressure drop is the local pressure drop manifested in each of the 11 junctions formed between adjacent fuel bundles, Fig.1. The principal role in this case is played by the value of the obturating surface in the junction of the two bundles.

As known, the local pressure drop emerges in the case of a local perturbation of the normal flow induced by: vortices, turbulences, flow area's geometry

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modification (brusque expansion of area, brusque contraction of area, divergent flow, convergent flow etc.), hydraulic resistances (orifices, grates, other obstacles) a.s.o.

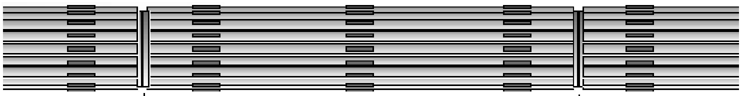


Fig. 1. Junctions between two CANDU fuel bundles.

For the flow of a fluid with density ρ (in kg/m^3) through a pipe element with cross section's area A (in m^2) at the average speed V (in m/s), the local pressure drop Δp_l (in N/m^2) is defined as:

$$\Delta p_l = \zeta_l \frac{\rho V^2}{2}$$

where ζ_l is a dimensionless coefficient [3].

The local pressure drop depends of turbulence by Reynolds number:

$$\mathrm{Re} = \frac{\rho V D_H}{\eta} = \frac{V D_H}{\nu}$$

where D_H is the hydraulic diameter (in m), η is the dynamic viscosity (in kg/m.s), and ν is the kinematical viscosity (in m^2/s) [3].

More exactly, for a turbulent flow and $\mathrm{Re} > 10^4$:

● **Brusque expansion**: in the case of a brusque expansion from the small cross section A_0 to the large cross section A_1, we have the Borda-Carnot formula [3]:

$$\zeta_l = \frac{2\Delta p_l}{\rho V_0^2} = \left(1 - \frac{A_0}{A_2}\right)^2$$

● **Brusque contraction**: in the case of a brusque contraction from the large cross section A_1 to the small cross section A_0, we have the approximating Idelcik formula [3]:

$$\zeta_l = \frac{2\Delta p_l}{\rho V_0^2} = 0.5\left(1 - \frac{A_0}{A_1}\right)^{\frac{3}{4}}$$

If the fluid flows from a large cross section A_1 (in m^2) to a small cross section A_2 (in m^2) by an intermediate orifice of section A_0 (in m^2), then [3]:

$$\zeta_l = \left(1 + 0.707\sqrt{1 - \frac{A_0}{A_1}} - \frac{A_0}{A_2}\right)^2$$

● **Divergent flow**: in the case of a conic divergent flow from a small cross section A_0 (in m^2) (diameter D_0) to a large cross section A_1 (in m^2) at the divergent angle α (in degrees) upon the length l_d (in m) we have [3]:

$$n_1 = \frac{A_1}{A_0}$$

$$\frac{l_d}{D_0} = \frac{\sqrt{n_1} - 1}{2 \cdot tg\frac{\alpha}{2}}$$

$$\zeta_{l_0 > 0} = \frac{2\Delta p}{\rho V_0^2} = k_d \zeta_{dif, l_0 = 0}$$

$$\zeta_l \geq \varphi \approx 3.2k \cdot tg\frac{\alpha}{2} \cdot \sqrt[4]{tg\frac{\alpha}{2}}$$

where $\zeta_{dif, l_0 = 0}$ is calculated for the limit $l_0 / D_0 = 0$. For a turbulent flow with $\mathrm{Re} > 3 \cdot 10^5$ and $0^o < \alpha < 40^o$, we can use a "flare" coefficient φ, and [3]:

● **Convergent flow**: in the case of a conic convergent flow from a large cross section A_1 (in m^2) to a small cross section A_0 (in m^2) at the divergent angle α (in degrees) upon the length l_d (in m) we have [3]:

$$n_0 = \frac{A_0}{A_1}$$

$$\alpha_r = 0.01745\alpha$$

$$\zeta_l = \left(0.0125n_0^4 + 0.0224n_0^3 - 0.00723n_0^2 + 0.00444n_0 - 0.00745\right) \times \left(\alpha_r^3 - 2\alpha_r^2 - 10\alpha_r\right)$$

All these above discussed cases (but not only) are characteristic for the junction's plane and/or junction's region of two fuel bundles, the flowing cross section being calculated by the subtraction of the obturating surface from the pressure tube's cross section [4].

To analyse and minimize the lost of coolant's pressure (energy) at the ICN Pitesti, Romania, it was developed a general software application used to design and calculate the area of the obturating surface in the junction of two CANDU fuel bundles, for rotations, degree by degree, in the $[0^{\circ}–360^{\circ}]$ domain [5].

2. Analyzed cases

In an innocent presentation, a fuel bundle is formed by a number of fuel elements (rods) and two end plates, Fig. 2.

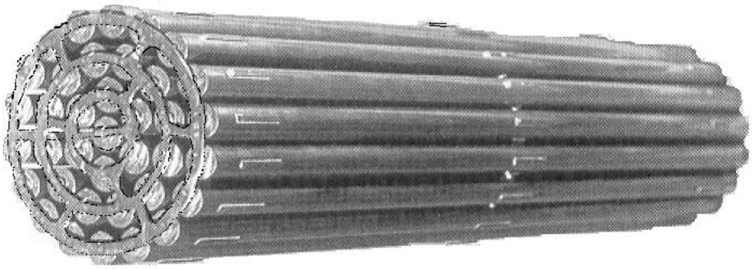


Fig. 2. Standard CANDU fuel bundle (37 elements).

So, if one accepts, by "definition":

(Elements) (end Plate) (Bundle)

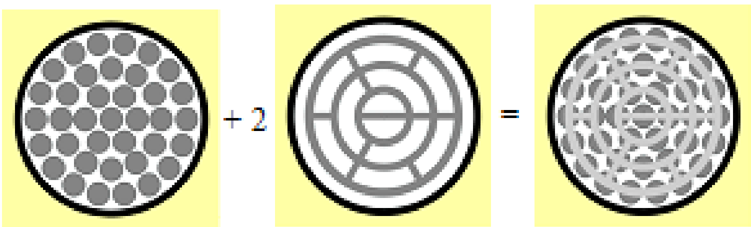


Fig. 3. Fuel bundle's "definition".

then we analysed the combinations of the next four types of fuel bundles (where: 37, 43, 52 = number of elements; S = Standard end plate; M = Modified end plate):

● (E37S) + 2 (P37S) = (B37S)

Fig. 4. Fuel bundle with 37 elements and standard plates.

● (E37S) + 2 (P37M) = (B37M)

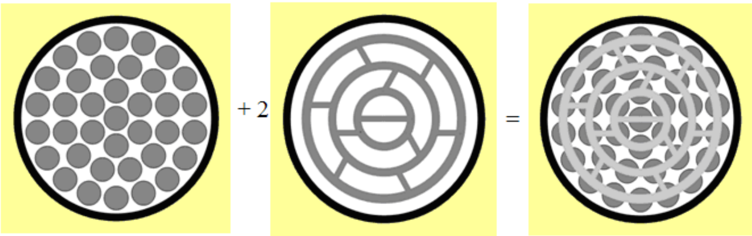


Fig. 5. Fuel bundle with 37 elements and modified plates.

● (E43S) + 2 (P43S) = (B43S)

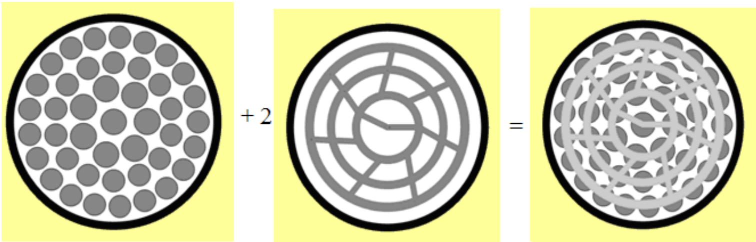


Fig. 6. Fuel bundle with 43 elements and standard plates.

● (E52S) + 2 (P52S) = (B52S)

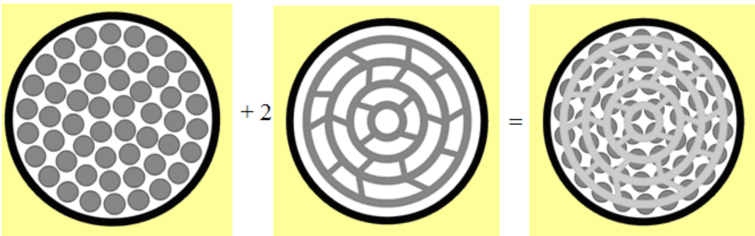
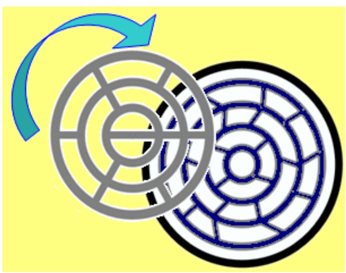


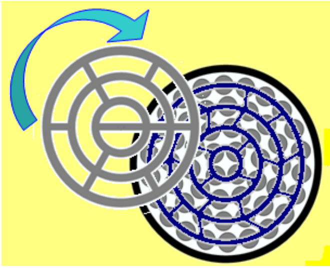
Fig. 7. Fuel bundle with 52 elements and standard plates.

More exactly, we analysed 68 types of possible interpretation of the obturating surface's geometry in the junction's region, formed by combinations as:

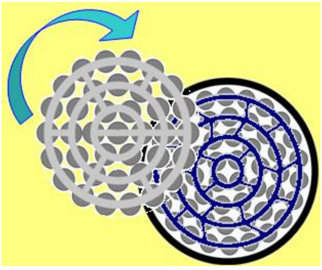
● End Plate + End Plate (in the junction's plane);



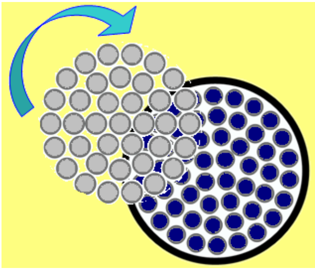
● End Plate + Fuel Bundle (in the junction's region);



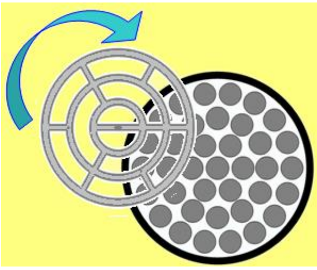
● Fuel Bundle + Fuel Bundle (in the junction's region);



● Fuel Elements + Fuel Elements (in the junction's region);



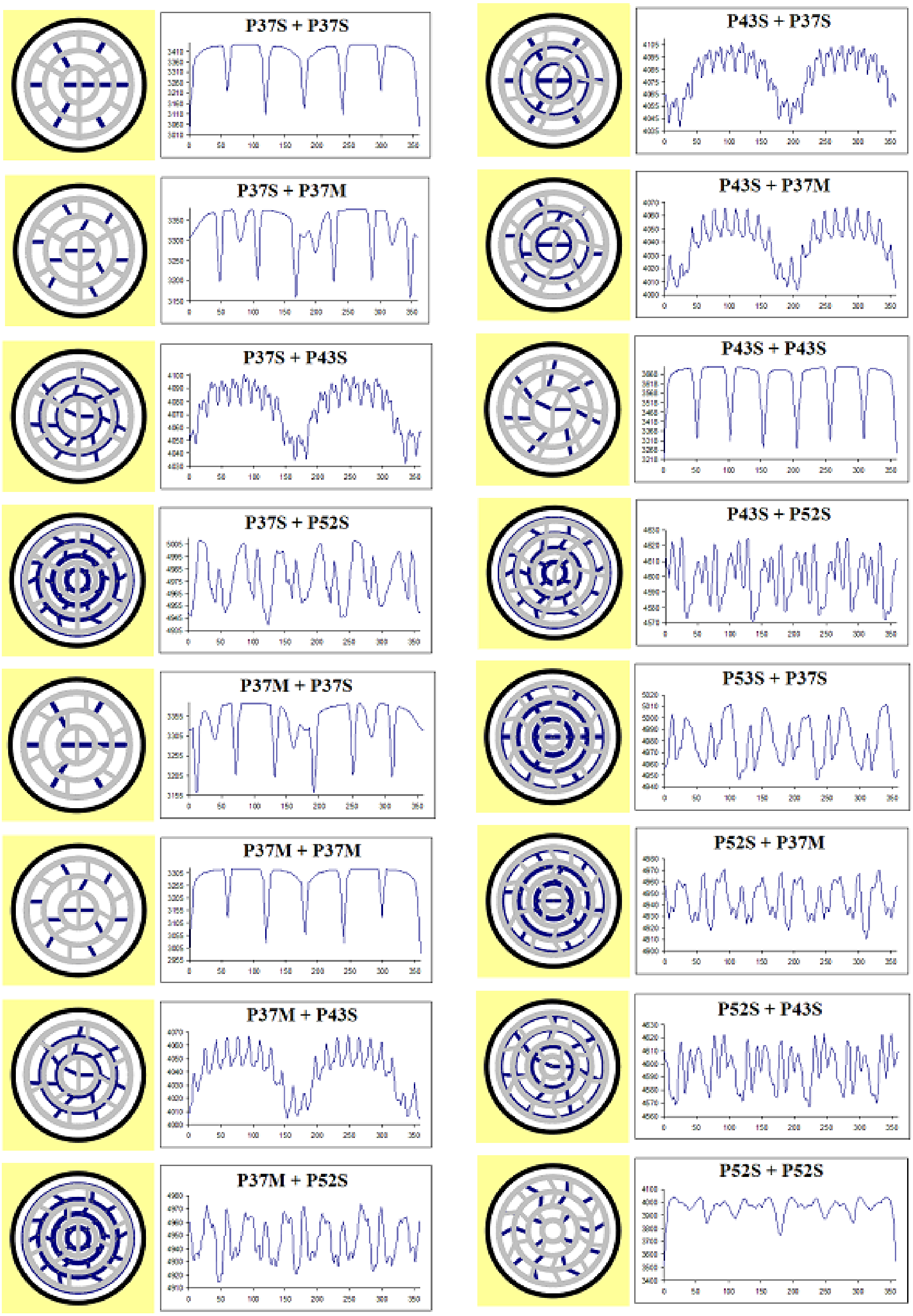
● End Plate + Fuel Elements (to find the optimum montage position).



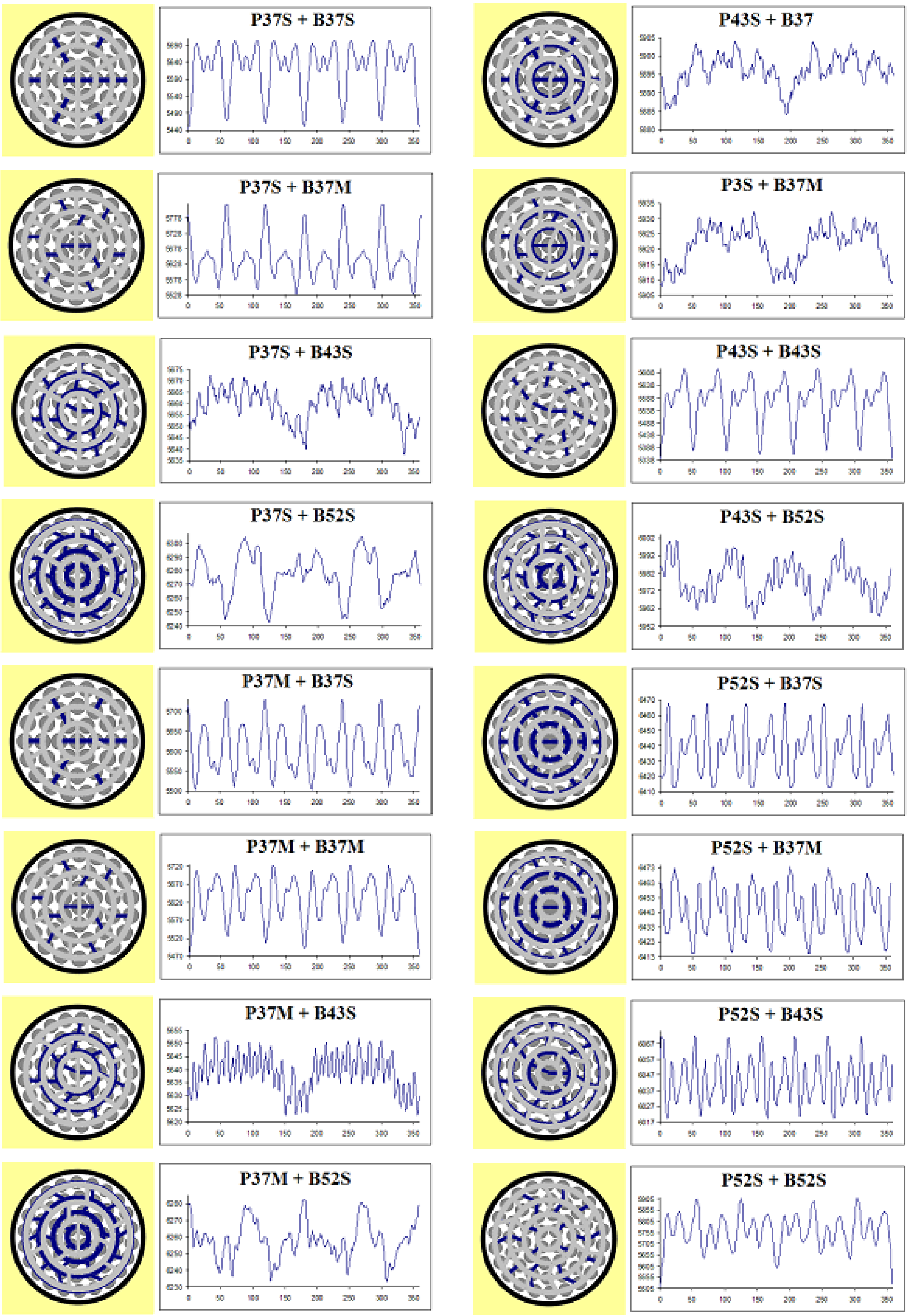
3. Graphical results

The next figures represent the graphical results for the variations of the obturating surfaces of the junctions, "viewed" by the fluid, at a [0–360°] rotation, degree by degree:

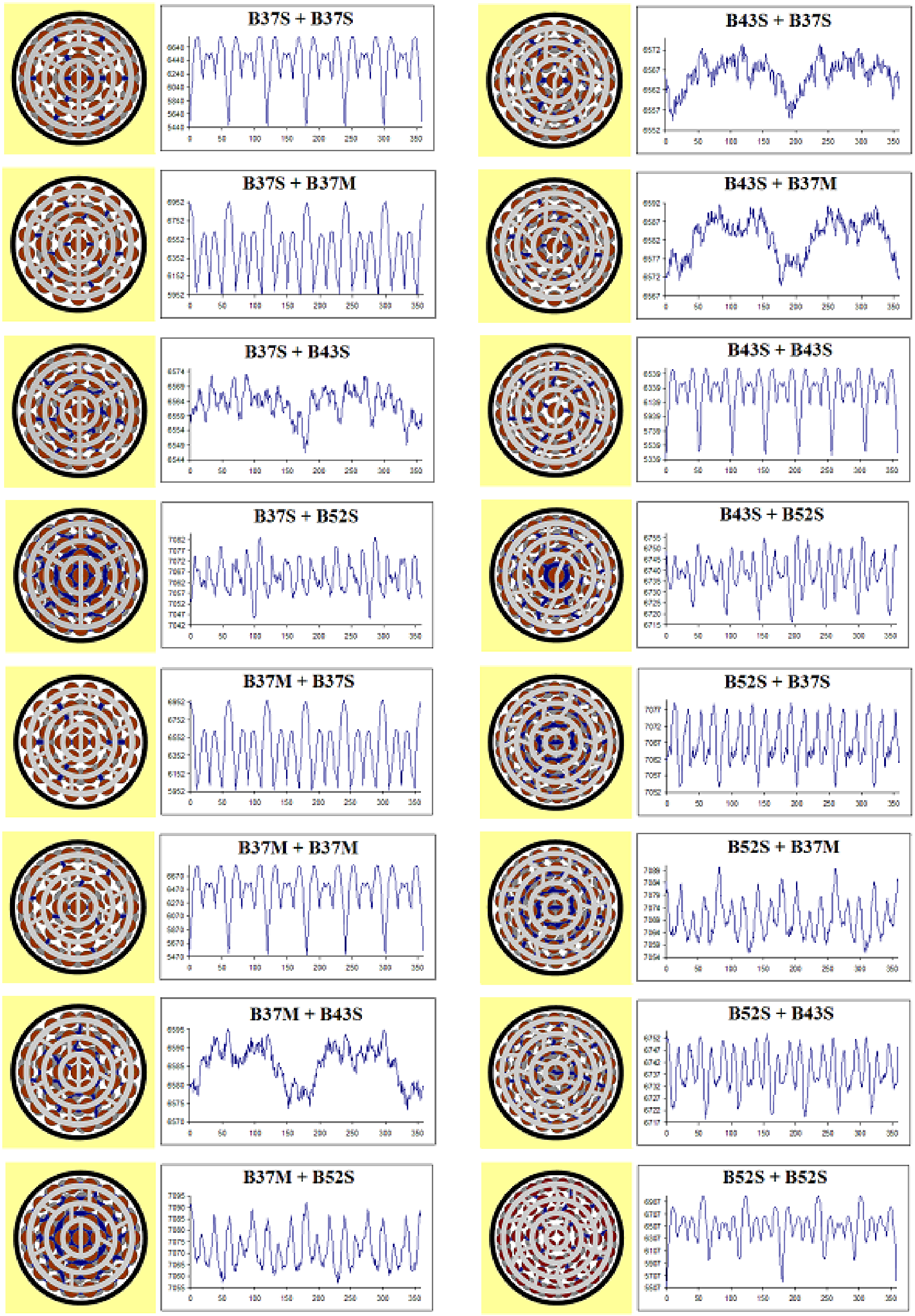
End Plate + End Plate



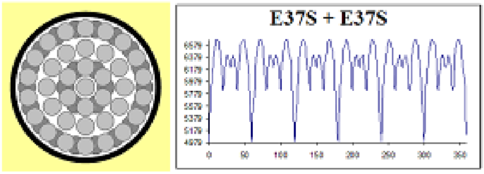
End Plate + Fuel Bundle

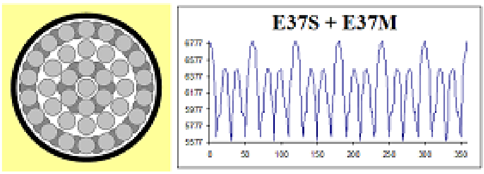


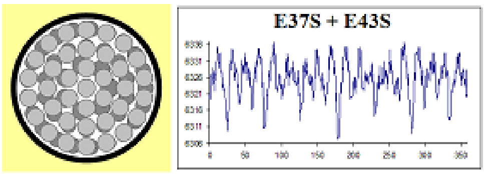
Fuel Bundle + Fuel Bundle

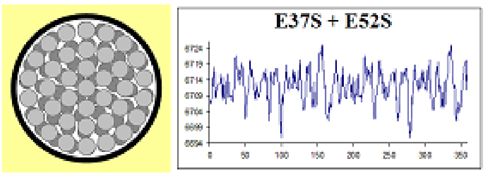


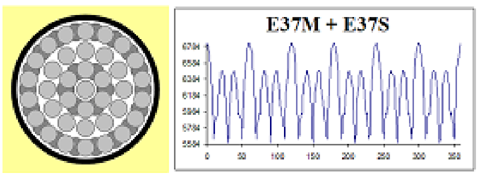
Fuel Elements + Fuel Elements

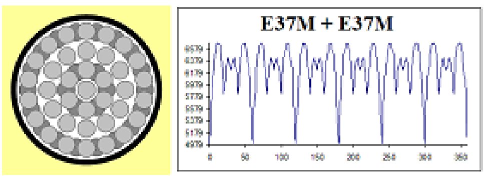


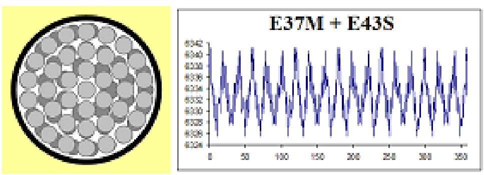


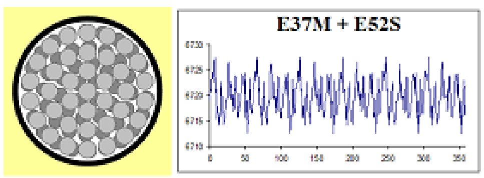


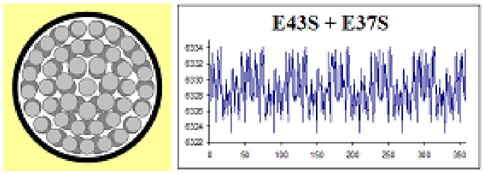


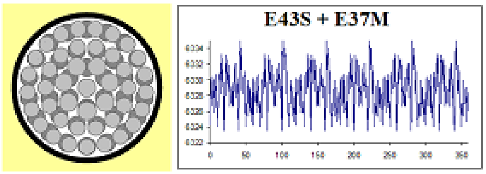


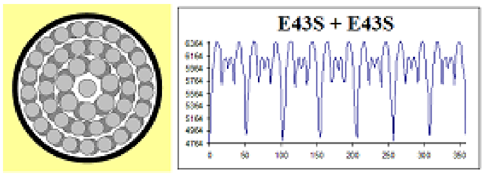


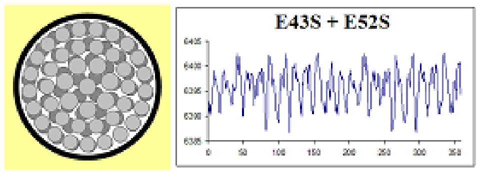


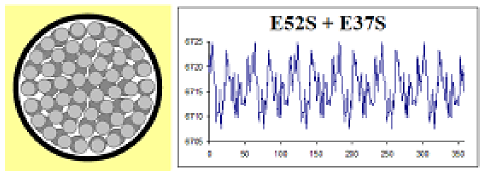


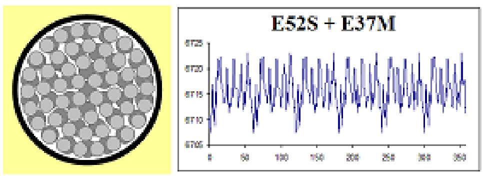


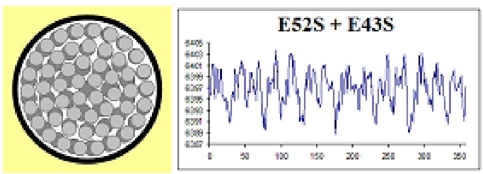


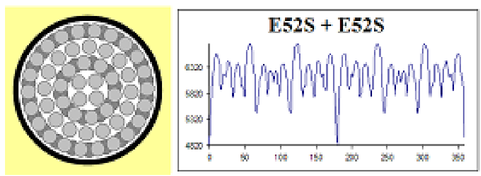




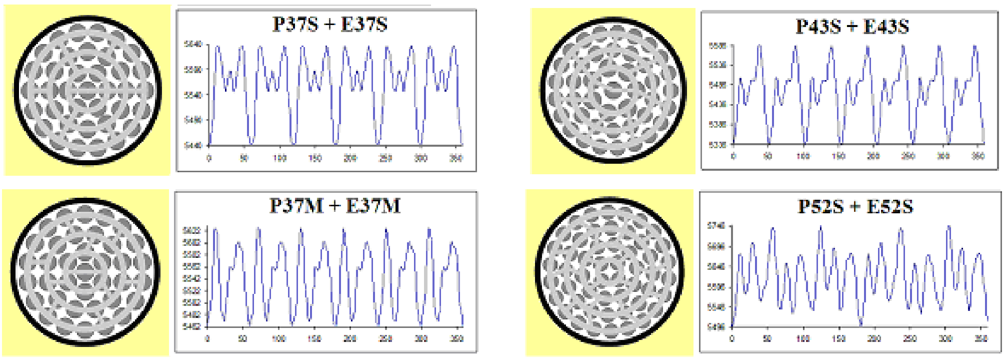








End Plate + Fuel Elements



Conclusions

Why so many combinations?

● In the first instance, because in an experimental test one can insert a “type B” fuel bundle in a string of “type A” fuel bundles, as in Fig. 8.

● In the second instance, because the so named “in junction pressure drop” may take place (or may be measured) not strictly in “a geometrical plane” (without thickness) but in “a few axial extended region” on both sides of this plane.

● In the last case, the misalignment of fuel elements may be more important then the role played by the misaligned end plates (in fact, what hydraulic resistance “sees / feels” the coolant in the junction’s region?).

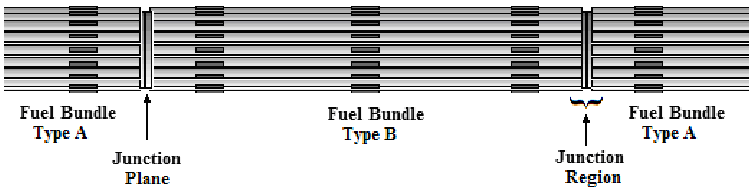


Fig. 8. Junctions between two types of fuel bundles.

In all the above cases we have periodical variations of the obturating surfaces.

Therefore, at a random fuelling of the 12 Fuel Bundles in the horizontal CANDU channel, the most important obturating surface’s values are: the minimum, the average, the maximum and the most probable.

For this reason, qualitative and quantitative, the above results may be used to analyse and explain the experimental data obtained in the pressure-drop tests.

An improved version of the above mentioned calculus program was used in [6].

Today, the authors work for a full new, more accurate and intuitive software application.

R E F E R E N C E S

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