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# THERMAL-HYDRAULIC DESIGN OF A FUEL MINI-PLATE IRRADIATOR FOR THE IEA-R1 RESEARCH REACTOR

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## Abstract

A mini-plate irradiator was designed for IEA-R1 research reactor. A parametric study was carried out with a thermal-hydraulic model to obtain the minimum necessary flow rate through the mini-plates to remove the heat generated during the irradiation. The heat fluxes in the mini-plates were calculated using neutronic codes. An experimental procedure and tests were performed to obtain the geometric characteristics of a Flow Limiting Plate (FLP) to provide suitable flow rate through the mini-plates. The tests were performed in an experimental circuit and the results were used to build pressure drop versus flow rate curves (PD x Q). The desired geometry of the FLP was obtained when the irradiator pressure drop was the same to the fuel element pressure drop for the minimum necessary flow rate.

## 1. INTRODUCTION

IPEN IEA-R1 is a 5 MW pool type research reactor, mainly used for radioisotope production for medical application. It uses MTR (Material Testing Reactors) fuel elements in the core and each fuel element has 18 fuel plates assembled on two lateral support plates, forming 17 independent flow channels. Usually, these fuel plates are made of $U_3O_8$ – Al or $U_3Si_2$ – Al in the meat and an Aluminium cladding. To produce fuel elements with better performance (high burn-up, high corrosion resistance, small swelling, etc.) it is necessary to know the behaviour of fuel plates after their irradiation in the reactor. Irradiation devices are used to irradiate mini-plates of fuel to provide material for post-irradiation studies. Mini-plates with different concentrations, enrichments, widths and types of fuel ($U_3O_8$ – Al or $U_3Si_2$ – Al) are irradiated during a planned period of time. After that, these mini-plates are removed and checked.

This work presents the thermal-hydraulic design of a device for mini-plates irradiation in the IEA-R1 reactor core. Calculations were performed to obtain the minimum flow rate necessary to cooling the mini-plates during the irradiation. Experiments were performed to define the geometric characteristics of a Flow Limiting Plate to assemble inside the irradiator to limit the flow rate to the calculated value in order to reduce the bypass flow rate from active reactor core.

## 2. PARAMETRIC AND EXPERIMENTAL STUDIES

A thermal-hydraulic model was developed by Umbehaun [1-2]. This model was used to perform a parametric study to verify the behaviour of mini-plates surface temperature as a function of the parameters: a) flow rate through the irradiation device; b) active width of the mini-plates; c) irradiation position in the core; d) type of fissil material; and e) concentration of fissil material. The surface temperature limit is 95°C. The resulting equations of the model (unidimensional conduction and convection heat transfer equations for rectangular flow channels) were solved with EES (Engineering Equation Solver), the commercial software developed by Klein et al. [3]. The mini-plate heat generation depends on the irradiation position in the core and it is calculated using the CITATION [4] and LEOPARD [5] codes. Figures 1 and 2 shows a draw of the mini-plate irradiator and reactor core. Table 1 shows the results of the parametric study and the most critical condition of flow rate is highlighted.



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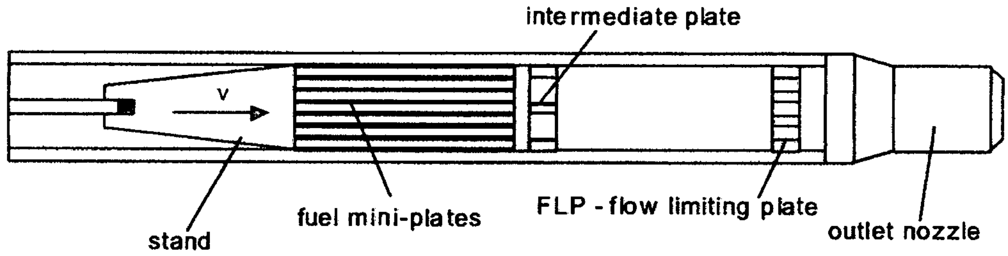
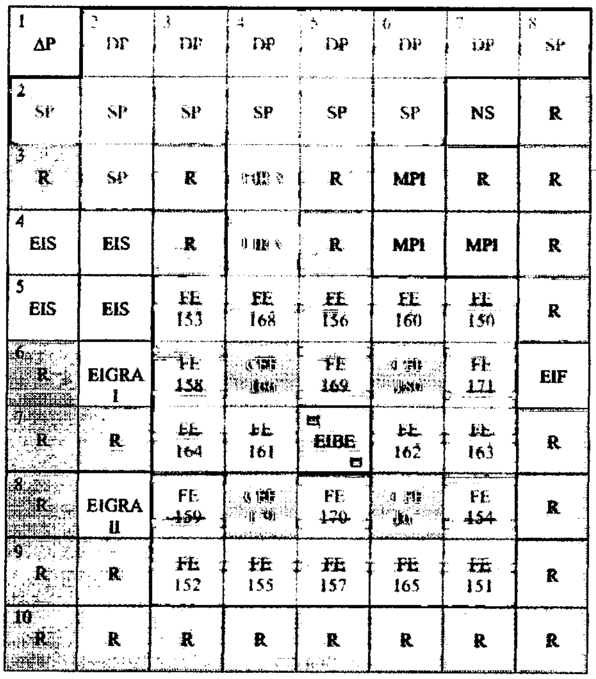



*Figure 1. Mini-plate Irradiator.*




**LEGEND**

ΔP = core pressure drop measurement
DP = double plug
SP = single plug
NS = neutron source
R = graphite reflector
FE = fuel element
CFE = control fuel element
EIGRA's = irradiators
EIS = irradiator
EIBE = irradiator
GI = irradiator
EIF = irradiator
EIRA = irradiator
MPI = Mini-Plate Irradiator Positions

*Figure 2. IEA-R1 core components and mini-plate irradiator positions.*

Table 1 – Minimum flow rate to cooling the mini-plates.

| active width (mm) | Core Position | $U_3O_8$-Al (3.0 gU/cm$^3$) $Q_{min}$(m$^3$/s)/(m$^3$/h) | $U_3Si_2$-Al (3.0 gU/cm$^3$) $Q_{min}$(m$^3$/s)/(m$^3$/h) | $U_3Si_2$-Al (4.8 gU/cm$^3$) $Q_{min}$(m$^3$/s)/(m$^3$/h) |
|---|---|---|---|---|
| 20 | 36 | 1.06 x 10$^{-3}$ / 3.8 | 1.44 x 10$^{-3}$ / 5.2 | 2.03 x 10$^{-3}$ / 7.3 |
| 20 | 47 | 1.97 x 10$^{-3}$ / 7.1 | 2.00 x 10$^{-3}$ / 7.2 | 2.83 x 10$^{-3}$ / 10.2 |
| 20 | 46 | 2.42 x 10$^{-3}$ / 8.7 | 2.42 x 10$^{-3}$ / 8.7 | 3.42 x 10$^{-3}$ / 12.3 |
| 40 | 36 | 1.42 x 10$^{-3}$ / 5.1 | 1.42 x 10$^{-3}$ / 5.1 | 1.94 x 10$^{-3}$ / 7.0 |
| 40 | 47 | 1.97 x 10$^{-3}$ / 7.1 | 1.94 x 10$^{-3}$ / 7.0 | 2.69 x 10$^{-3}$ / 9.7 |
| 40 | 46 | 2.42 x 10$^{-3}$ / 8.7 | 2.42 x 10$^{-3}$ / 8.7 | 3.33 x 10$^{-3}$ / 12.0 |

Experiments were performed to obtain the geometric characteristics of a Flow Limiting Plate (FLP) to be used in the irradiator. The main function of FLP is to provide a suitable flow rate to the mini-plates avoiding unnecessary bypass flow from active core. It was designed maintaining the same core pressure drop in the irradiator for the minimum flow rate (Q=3.42 x $10^{-3}$ $m^3/s$). The core pressure drop (PD=7.35 $kN/m^2$) was experimentally measured using an instrumented dummy fuel element for 3000 gpm (0.19 $m^3/s$) total flow rate in the reactor primary system. Irradiator with mini-plates and FLP was assembled in a test section simulating the reactor pool of the experimental circuit shown in Fig. 3. All tested FLP's are 16 mm thick. The flow rate through the irradiator was measured by a calibrated orifice plate and a differential pressure transducer (DPT), and the irradiator pressure drop was also measured by a DPT.

Eighteen irradiator configurations (A to R) were tested and the results are shown in Figs. 4 and 5. Considering a quadratic function between pressure drop and flow rate (PD = K x $Q^2$), we can calculate the irradiator pressure drop coefficient K. Substituting PD and Q in the previous equation we obtain K = 6.3 x $10^8$. Figure 4 shows the irradiator pressure drop versus flow rate for all the tests. Figure 5 shows the K coefficient versus FLP flow area A and the fitted curve K = f (A). The FLP's that produced the desired results were tested in configurations I (A= 981,19 $mm^2$) and J (A=934.82 $mm^2$ ; 9 holes of 11.5 mm). Substituting K = 6.3 x $10^8$ in the fitted curve we obtain A= 1040 $mm^2$, corresponding to 9 holes of 12.0 mm, near to the FLP of J configuration. Figure 6 shows a photograph of the irradiation device with its internals.

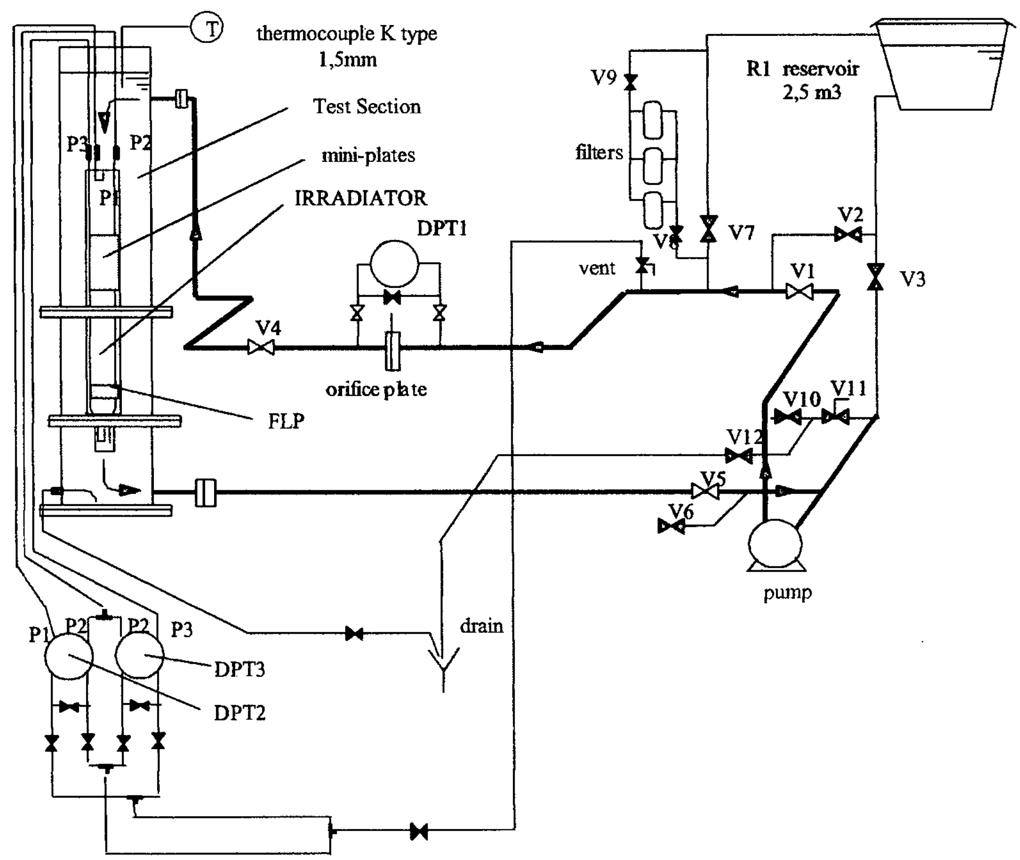



*Figure 3. Experimental circuit used for tests.*

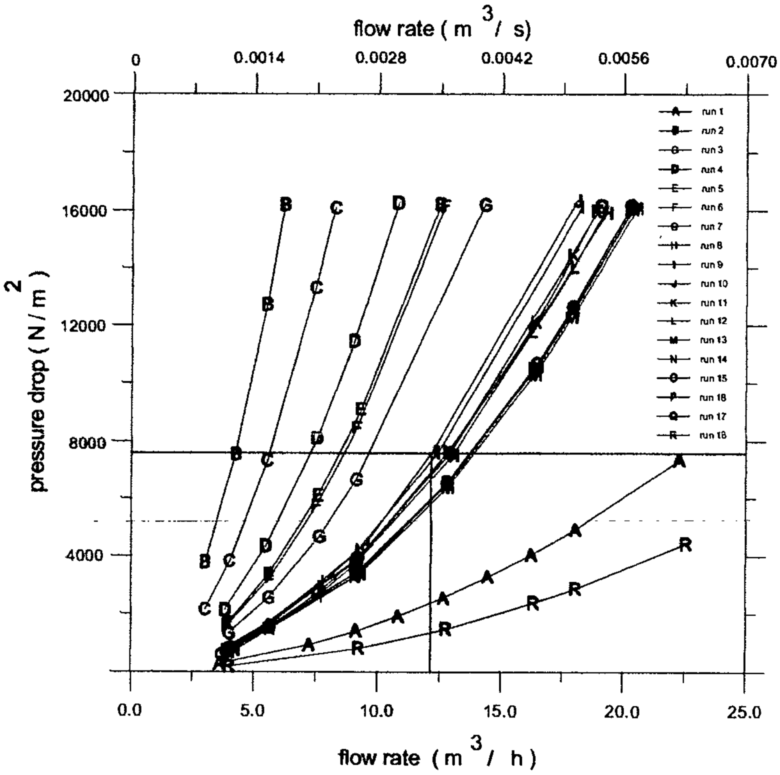



*Figure 4. Experimental results: Pressure Drop (PD) versus Flow Rate (Q).*

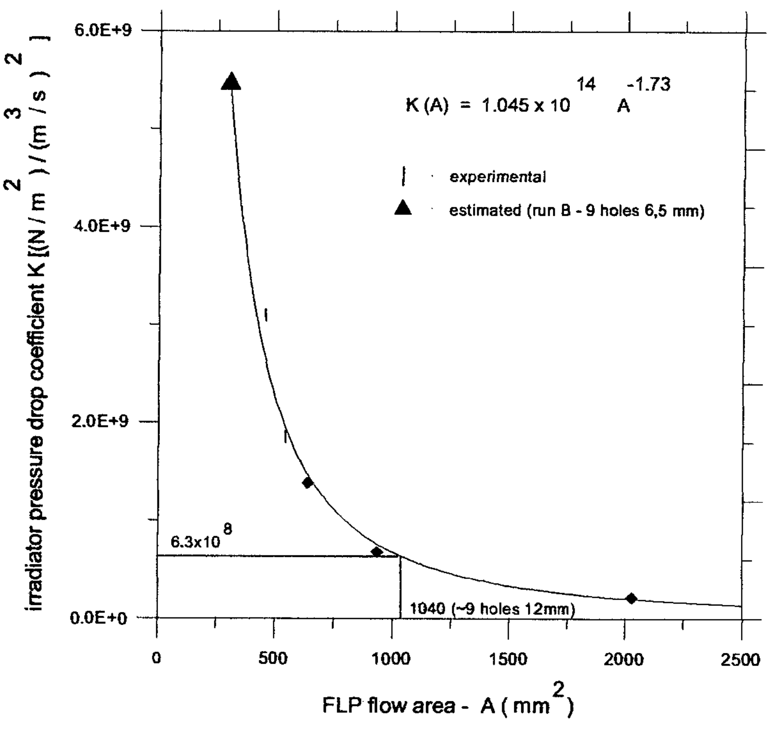



*Figure 5. Experimental results: Pressure Drop Coefficient (K) versus FLP flow area (A).*

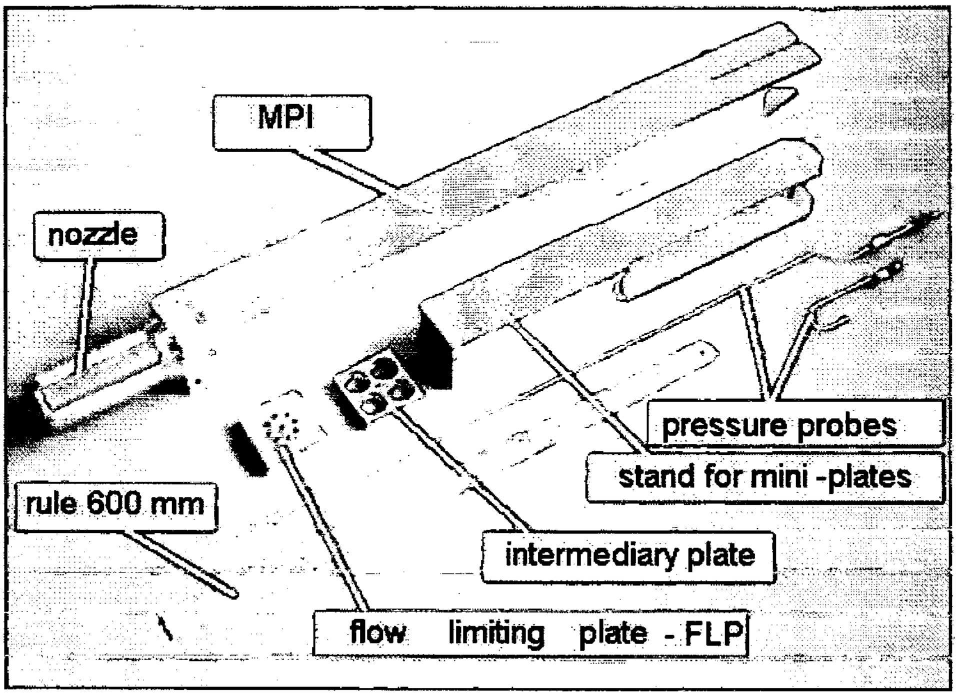



*Figure 6. Mini-plate irradiator with its internals.*

## 3. CONCLUSIONS

A thermal-hydraulic design of a mini-plate irradiator was performed. Flow rate requirements for cooling the mini-plates during the irradiation in the reactor core were obtained in a parametric study. The minimum flow rate required for the most critical irradiation condition is $3.42 \times 10^{-3}$ $m^3/s$ (12.3 $m^3/h$). Experiments were carried out to obtain the geometric characteristics of a flow limiting plate (FLP), so as to provide this minimum flow rate through the irradiator. This FLP has 9 holes of diameter 11.5 mm, corresponding to a flow area equal to 934.82 $mm^2$. A curve relating pressure drop coefficient K and FLP flow area was obtained as a powerful tool to design other irradiators with different flow rate requirements.

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