# TRANSIENT HEAT TRANSFER IN A FLUIDIZED BED NUCLEAR REACTOR

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## ABSTRACT

A preliminary heat transfer analysis for the fuel elements in the fluidized bed nuclear reactor under transient is performed. It is seen that even under extreme adverse conditions, the integrity of the fuel elements is conserved.

## INTRODUCTION

A reactor design based on the fluidized-bed concept has been proposed |1|. The reactor is modular in design, an idea that was also proposed later by others. A reactor of any size can be designed from the basic module. The costs of development, design, fabrication, and licensing will therefore be associated with the basic standard module and are consequently reduced.

The proposed reactor concept is especially adaptable as a small reactor. Developing countries with small electrical grids or with a need for water desalination and some industrial countries where small additions to existing grids are now being considered or where urban and process heating are being planned are showing a great interest in the small reactors. A scaledown of existing large reactors that are unecononical and a new reactor concept that alters traditional scaling laws have become necessary.

The proposed reactor is so simple in design that even developing countries with modest industrial infrastructures can develop, design, and finally construct such a reactor. This concept is currently being developed on the basis of slightly enriched uranium that is moderated and cooled by light water under pressure. Future studies will include the use of organic coolants with a thorium fuel cycle. The use of natural uranium with heavy water will also be of great interest.

The proposed reactor fulfills the objectives of design simplicity, inherent safety, economy, standardization, shop fabrication, easy transportability, and high availability.

## REACTOR DESCRIPTION

The nuclear reactor based on the fluidized bed concept proposed is modular in design. The upper part of the reactor module which include the core and the steam generator consists of a 25 cm diameter fluidizing tube being circumscribed by a hexagonal channel. The lower part of the module consist of a 10 cm diameter fuel chamber surrounded by a circular channel which in turn is covered by a graphite jacket.

An anel is formed between the fluidizing tube and hexagonal channel and at its extension between the fuel chamber and the circular channel where the coolant flows down the module. In the upper part of the core, a movable sieve acting as a fluidized bed level limiter separates the core from the steam generator. A cylindrical neutron absorber shell connected to the sieve moves along with it. A steam generator of the shell and tube type is integrated into the upper part of the module.

Inside the fuel chamber exist the spherical fuel elements of about 0.8 cm in diameter made of slightly enriched uranium dioxide cladded by zircaloy. The fresh fuel elements are fed into the reactor core through the the hollow shaft of the level limiter. The botton of the fuel chamber is provided with a fuel discharge valve. The valve is operated by a hydraulic system allowing the fuel to be discharged from the fuel chamber into a permanently cooled storage tank. The module is provide with a pressurizer system which is to keep the pressure a constant, and a depressurizer valve which leads the steam to the condenser intended to be used for reducing the pressure to allow the opening of the valve for refuelling purposes.

The cooled coolant gaining pressure in the pump enters the combustion chamber after crossing the perfurations in the distributer. It rises in the module and after exceeding a certain velocity limit, carries with it the fuel pellets into the reactor core, and thereafter fluidizing them. The coolant after gaining heat from the core, transfers it to the steam generator, returning to the pump through the anel space.

The reactor is surrounded by a graphite reflector and a biological shield.

## STEADY STATE HEAT TRANSFER EVALUATION

The thermal-hydraulic characteristics of the reactor determine the fuel integrity, cladding integrity, coolant exit conditions, pumping requirements, and temperature feedback for reactor neutronics calculations. The steady-state heat transfer bechavior of the reactor under various design conditions has been studied and published previously |2|. The HOTBALL computer program was developed in order to calculate the thermalhydraulic parameters of the fluidized-bed nuclear reactor.

The coolant temperature distribution along the height of the reactor for flow rates of 25 ℓ/s and 30 ℓ/s under exaggerated heat generation conditions is evaluated. The distribution of the fuel pellet center temperature along the reactor height for a nominal flow rate of 25 ℓ/s is also calculated. The maximum difference in fuel and clad surface temperature is - 5°C. The temperature drop from clad surface to fluid varies between 2°C at the bottom and 5°C at the top of the reactor. The maximum temperatures are far below reactor safety limits.

Due to a high convective heat transfer coefficient and large heat transfer surface, the maximum power extracted from the reactor core is not limited to the material temperature limits, but to the maximum mass flow of coolant, which corresponds to the desired operating porosity.

The heat transfer design will be based on the minimum critical porosity. Fuel and coolant temperatures will decrease as burnup increases, since the reactor will operate at higher porosities. The operational procedure is to secure a low coolant flow through the reactor within a certain period of time after shutdown. Preliminary calculations show, however, that in case of a loss-of-flow accident or even a LOCA, in which immediately after shutdown the decay heat generation rate is 6.7% of the average operating power, no safety problem exists because there is sufficient graphite to absorb the decay heat realesed and the decay heat is transformed to the water in the pool located under the reactor. The option of removing the fuel pellets from the core by opening the fuel discharge valve always exists.

## HEAT TRANSFER UNDER TRANSIENT CONDITIONS

An analysis of the 8 mm diameter spherical fuel elements was made using the lumped capacity technique. For the preliminary calculations, the method is expected to be adequate since under accident conditions the Biot number is very small ($Bi < 0.1$). An energy balance on the fuel element with volumetric thermal source strength $q'''(t)$ due to fission, yields the following equation

$$\frac{dT(t)}{dt} + \frac{6h(T-T_f)}{\rho_s Cp_s d} = \frac{q_o''' e^{\alpha t}}{\rho_s Cp_s} \qquad (1)$$

where T is the time dependent fuel element temperature. $T_f$, $\rho_s$, $Cp_s$, and d are coolant temperature, density, specific heat , and diameter of the fuel element respectively. The reactor power varies exponentially with a period of $1/\alpha$. The operating volumetric heat generation is assumed to be 145 W/cm$^3$.

Equation (1) yields a solution in the following form

$$T(t)-T_f = \frac{Q_o e^{\alpha t}}{\alpha + Ah} + \left|(T_o-T_f) - \frac{Q_o}{\alpha+Ah}\right| e^{-Aht} \qquad (2)$$

where

$$A = \frac{6}{\rho_s Cp_s d}, \qquad (3)$$

$$Q_o = \frac{q_o'''}{\rho_s Cp_s} \qquad (4)$$

and $T_o$ is the initial fuel temperature.

The average coolant temperature increase is evaluated by equating the convecting heat transfer to the increase in internal energy of the coolant. It yields the following equation:

$$T_w - T_f = \frac{Bh}{u} (T(t)-T_f) \qquad (5)$$

Where $T_w$ is the heated coolant temperature, u is the superficial coolant velocity, and

$$B = \frac{6M}{\rho_w Cp_w d} \qquad (6)$$

M being fuel mass in the module and $\rho_w$ and $Cp_w$ refer to the coolant.

The accident is assumed to occur when the reactor is in normal operating condition, when the fuel and coolant temperatures are 320°C and 310°C respectively. Figure 1 shows the fuel and coolant temperature increases after hypothetical accidents where the convective heat transfer coefficient may vary from h=4 Watt/cm$^2$ °C to burnout condition of h=0.1 and extreme condition of fuel element finding itself in a minimum heat transfer condition of conduction to static vapor atmosphere of h=0.0005. Fig 2 shows the increase in coolant temperature resulting from a condition where all the fuel elements simultaneously behave in such a manner. It is seen that even under such improbable adverse conditions, the transients will not cause sufficient increase in temperatures to do any damage to the fuel elements.

## REFERENCES

|1| Sefidvash, F. "A Fluidized-bed Nuclear Reactor Concept", Nucl. Technol., 71, 527 (1985).

|2| Sefidvash, F. "Preliminary Thermal Design Calculations of the Fluidized Bed Nuclear Power Reactor", Atomkernenergie/Kerntechnik, 41, 45 (1982).

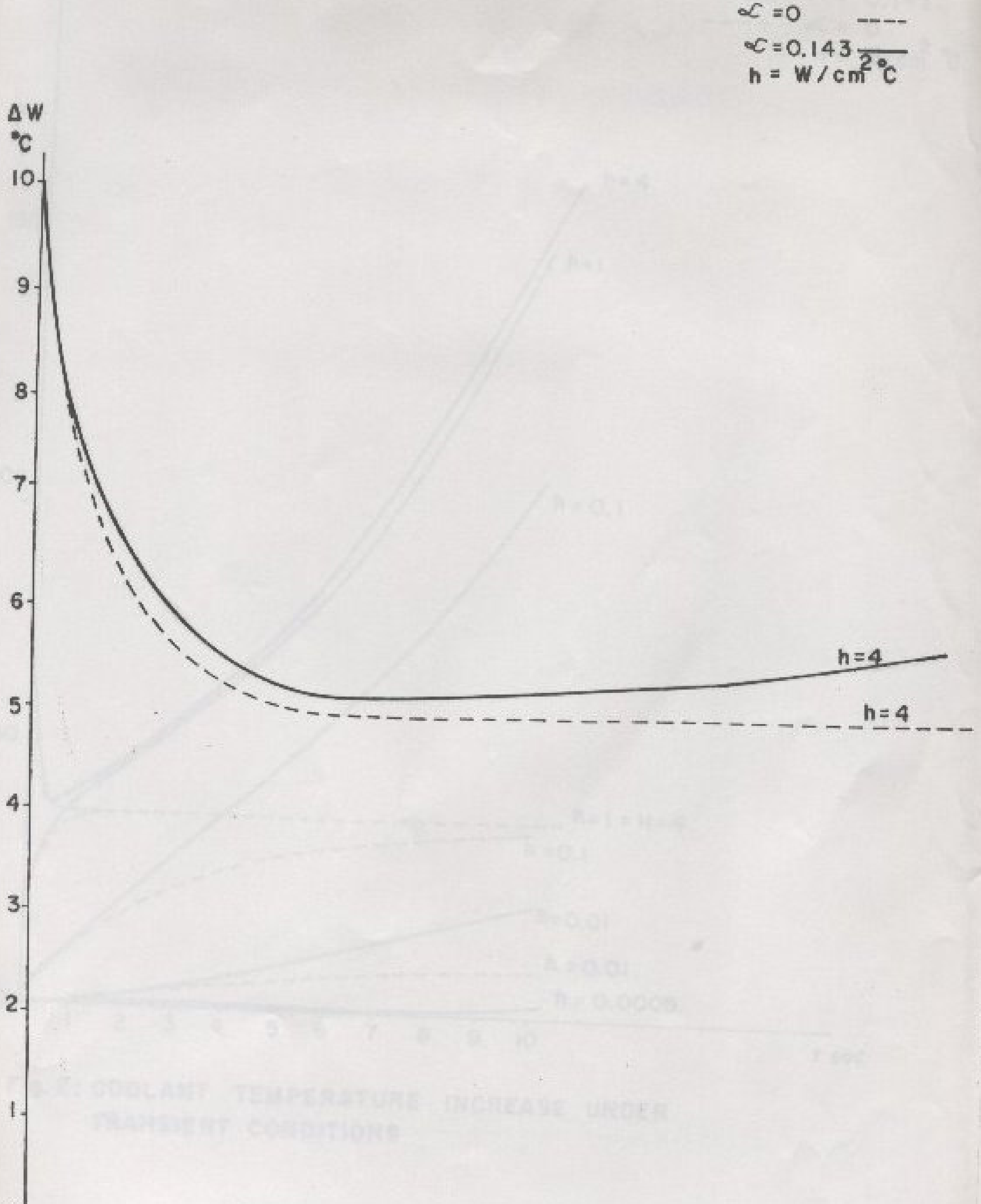

Fig.1a : FUEL TEMPERATURE INCREASE UNDER TRANSIENT CODITIONS

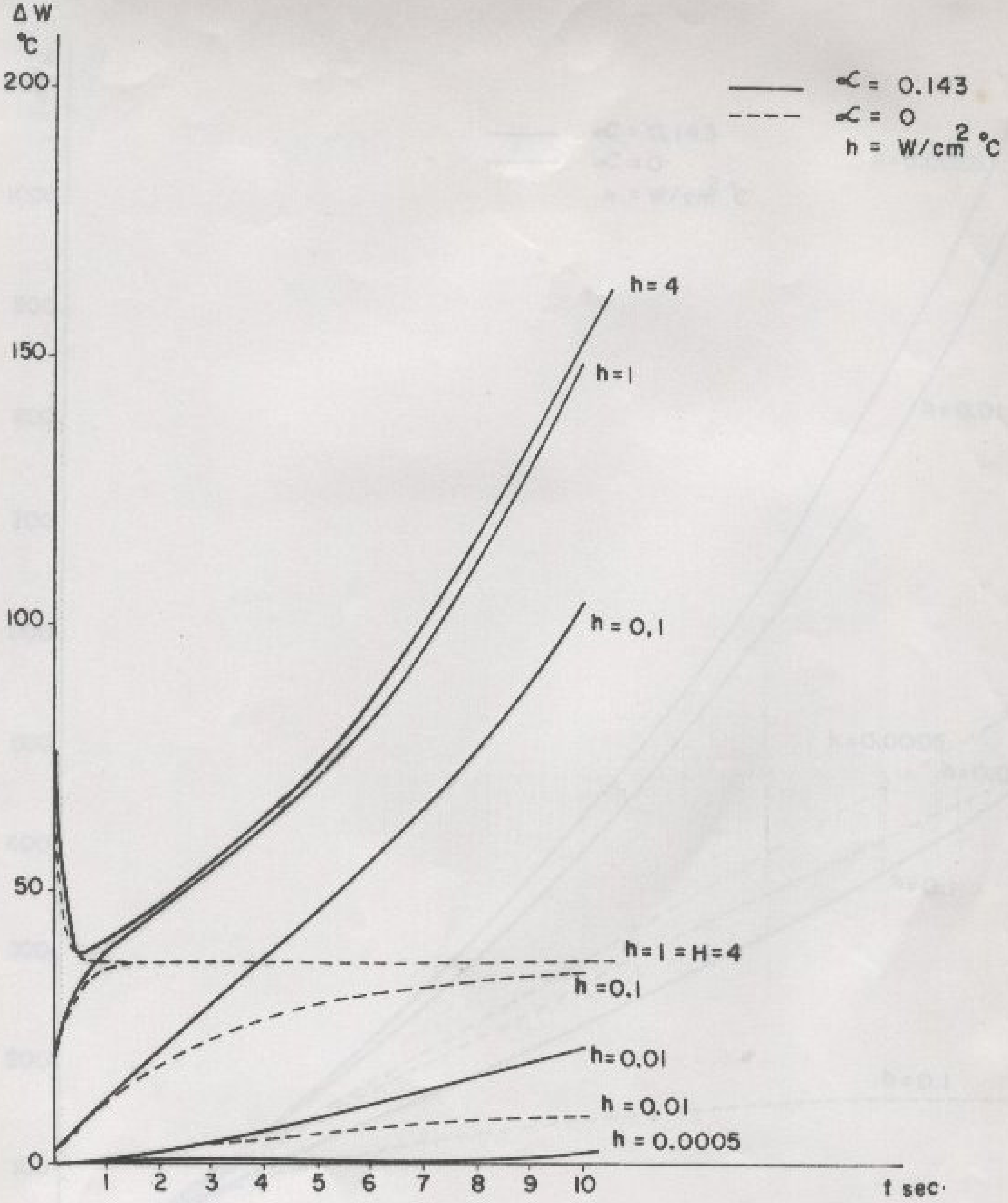

Fig. 2: COOLANT TEMPERATURE INCREASE UNDER TRANSIENT CONDITIONS

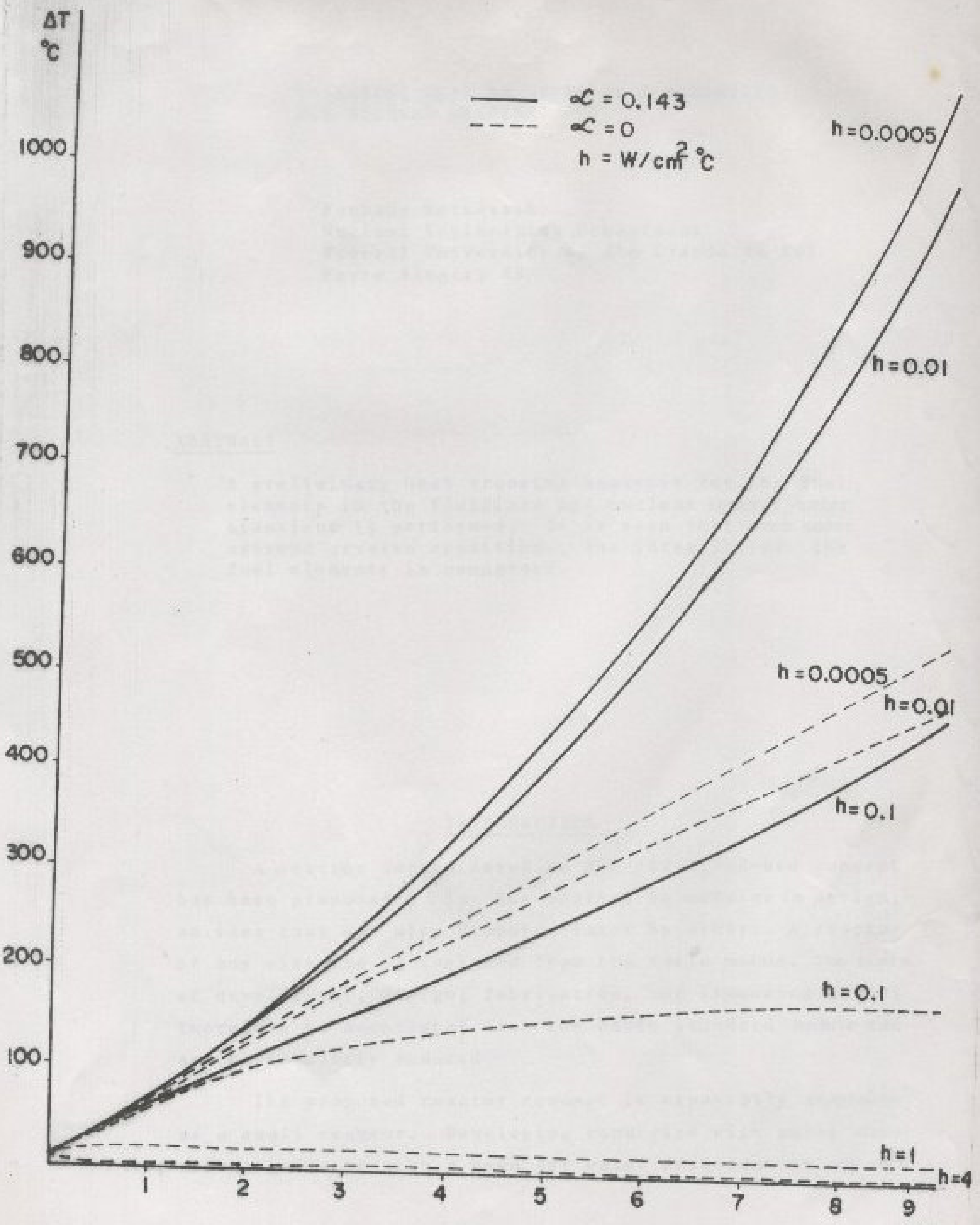

Fig.1: FUEL TEMPERATURE INCREASE UNDER TRANSIENT CONDITIONS