International Exchanges **JOINT PROJECT** Report

Personal Data - in confidence

- Please complete the report in layman's terms
- Please use font size 10
- Please do not exceed five pages of this report form
- Please submit any supplementary information as attachments and make a note on your covering letter that supplementary information is attached

1 Joint project reference no: FSU/JP

2 Collaborative partner's country: Russia

3 Joint Project report for year 1 (please delete as appropriate)

4 Name, title, home institution, address and email address of the UK Leader

Professor Sergei Sazhin
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5 Name, title, home institution, address and email address of the Overseas Leader

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Institute for High Temperatures
Russian Academy of Sciences
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Russia
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6 Title of Research:

A model for radiative and convective heating of fuel droplets

7 Brief outline of objectives of research

8 Achievements/findings as a direct result of the award

Please type up to 10 lines only

To develop simplified models for radiative and convective heating of liquid droplets, taking into account the transparency of droplets in the near infrared spectral range, finite thermal conductivity of the liquid and internal recirculations inside droplets, and to present the models in a form suitable for implementation into Computational Fluid Dynamics (CDF) codes. To investigate the mutual influence of radiative and convective heating and develop a unified model taking into account both processes.

To apply the developed models to multidimensional simulation of heat transfer, fluid dynamics and combustion processes in realistic internal combustion engines with specific emphasis on diesel engines.

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A simple model for heating and evaporation of non-isothermal droplets is suggested. This model is based on the parabolic approximation of the temperature profiles inside droplets. The d-squared law of droplet evaporation is modified to take into account droplet heating.
Comparison with numerical solutions of the transient problem for moving droplets shows the applicability of this approximation to modelling the heating and evaporation processes of fuel droplets in diesel engines. The simplicity of the model makes it particularly convenient for implementation into multidimensional CFD codes to replace the widely used model of isothermal droplets.

The boundary-value problem for calculation of differential absorption of thermal radiation is formulated based on the MDP0 (modified DP0) approximation. The solution of this problem is supplemented by simple analytical approximations for the normalised absorbed radiation power. The latter is used together with the analytical approximation for the efficiency factor of absorption, suggested earlier.
The resulting simplified model is applied to the specific problem of absorption of thermal radiation by a diesel fuel droplet. It is pointed out that the radial distribution of absorbed thermal radiation power is non-monotonic. The power absorbed in the droplet core is shown to be rather large and almost homogeneous. Also, the absorbed power is large in the vicinity of the droplet surface, but is minimal in the intermediate region. This result is related to absorption spectrum of diesel fuel.

Analytical solutions of the heat conduction equation inside a spherical droplet are obtained. The droplet is assumed to be heated by convection and radiation from the surrounding hot air --- a situation typical in many engineering applications. Initial droplet evaporation and the effects of time dependent gas temperature and convection heat transfer coefficient are taken into account. In the cases of constant and almost constant convection heat transfer coefficients, the explicit formulae for time dependent radial distribution of temperature inside droplets are obtained. In the case of arbitrary convection heat transfer coefficient the differential equations are reduced to the Volterra integral equation of the second kind. A numerical scheme for the solution of this equation is suggested.
The solution for constant convection heat transfer coefficient is applied to a typical problem of fuel droplet heating in a diesel engine. Results of the original measurement of the index of absorption of diesel fuel are used for the analysis. It is shown that finite thermal conductivity of fuel droplets and the effects of radiation need to be taken into account when modelling droplet heating in diesel engines.

9 Details of specific research outputs - papers published, conference presentations, others:

We would be pleased to receive copies of photographs as well as papers published and other material which could be used to publicise grant programmes.

The result has been presented in three research papers:

1. A simplified non-isothermal model for droplet heating, by L A Dombrovsky and S S Sazhin (to be published in International Communications in Heat and Mass Transfer. A copy is attached.

2. Absorption of thermal radiation in a semi-transparent spherical droplet: a simplified model, by L A Dombrovsky and S S Sazhin (submitted to International J of Heat and Fluid Flow). A copy is attached.

3. Transient heating of diesel fuel droplets, by S. S. Sazhin, P. A. Krutitskii, W. A. Abdelghaffar, S. V. Mikhalovsky, S. Meikle and M. R. Heikal (in preparation; to be submitted to International Journal of Heat and Mass Transfer). A copy of the draft version is attached.

10 Expected achievements/findings and outputs in the next project year or if this is your final year, please explain if there will be any further collaboration or applications for funding

Further development of the models and their implementation into a numerical code. This will include:

1. Investigation of the asymmetric thermal radiation absorption by a semi-transparent spherical particle.
This problem will be investigated in view of applications to the analysis of heating of fuel droplets by external asymmetric thermal radiation: the situation typical for diesel engines. At first the asymmetry of irradiation of droplets at the periphery of a spray will be investigated. Then Mie calculations will be performed to study the axisymmetrical absorption of thermal radiation by a droplet irradiated by a hemisphere. These calculations will allow us to find simple analytical approximations for the absorption of thermal radiation in droplets. These approximations will be generalizations of approximations obtained earlier for the case spherically symmetric irradiation of droplets. These new approximations will be used for calculation of absorption of thermal radiation in realistic diesel fuel droplets.
2. A self-consistent solution of the problem of transient heating of spherical droplets taking into account the development of a boundary layer around droplets. This effect is relevant to modelling the initial stage of droplet heating. The rigorous mathematical formulation will be given for this problem in the form of initial boundary value problem for heating equation with variable discontinuous coefficients. Transmission boundary condition will be considered on the interface between liquid and gas. Exact solution will be constructed using analytical methods for evolutionary partial differential equations.
3. Development of the kinetic approach for the analysis of diesel fuel droplet evaporation (additional task to be completed in collaboration with Professor A Kriukov.
4. Implementation of the models developed during the first year into a numerical code and their testing for the values of parameters typical for diesel engines.

11 Confidentiality

Some of the information contained in this report and its attachments may be communicated to outside parties. Please identify any sections which cannot be communicated and give your reasons for this.

N/A

Personal data on this form will be held and processed on the Society's computer. A summary of the Society's data protection policy, including the rights of subjects on which data are held, is obtainable from the Society (ref: DPSA/JHS).

12 Signature of UK Leader | | Date | **28 January 2003**

Please return this report form to the Exchanges Officer dealing with the administration of your award at:

International Section
The Royal Society
6-9Carlton House Terrace
LONDON
SW1Y 5AG

Financial Report

- This section of the report **MUST** be completed.
- If this is your final report, you do not need to complete the 'Estimate of Expenditure'.

Amount awarded for Year 1 £4970 **Amount awarded for Year 2:** £4970

Amount awarded for Year 3: £N/A **t applicable)**

STATEMENT OF EXPENDITURE: YEAR 1 of 2

Name	Destination	Date/Duration	Subsistence	Airfare + surf transp
L Dombrovsky	Brighton, UK		£1260.00	£265.96
P Krutitskii	Brighton, UK		£1260.00	£313.80
S Sazhin + M Heikal	Moscow, Russia	20-27 October 2002	£885.39	£742.80
			£	£
		Gift of Consumables (if applicable)	£	£
		TOTAL	£3405.39	£1322.56
			TOTAL SPENT	4727.95
			TOTAL UNDERSPENT	242.05

ESTIMATE OF EXPENDITURE FOR YEAR 2 of 2

Name	Destination	Date/Duration	Subsistence	Airfare
L Dombrovsky	Brighton, UK	25/05 – 14/06 (3 wks)	£1260	£375
P Krutitskii	Brighton, UK	July 2003 (3wks)	£1260	£375
A Kriukov	Brighton, UK	October 2003 (1 week)	£420	£375
S. Sazhin	Moscow, Samara (Russia)	November 2003 (12 days)	£672	£475
		Gift of Consumables (if applicable)	£	£
		TOTAL	£3612	£1600
			TOTAL ESTIMATED	4970
			UNDER SPEND TO CARRY OVER	242
			TOTAL REQUESTED	5212

Award payable to: School of Engineering, The University of Brighton, Brighton BN2 4GJ

UK Project Leader's Signature: Date: 28 January 2003

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International Section Grant Questionnaire

We would be grateful if you could spare the time to fill in this questionnaire to help our monitoring efforts. Please feel fr ee to add comments in the space provided.

1 Please rate the standard of the administration of your award by the Royal Society on a scale of 1 to 7 by ,arking one of the following boxes:

7 = outstanding, 6 = excellent, 5 = very good, 4 = good, 3 = average, 2 = weak, 1 = poor

x						
7	6	5	4	3	2	1

2 Where did you hear about the grant programme?

☐ Research Fortnight ☐ Nature ☐ New Scientist ☐ Other publication (please specify)
☐ Publicity sheet ☐ Web x☐ Word of mouth ☐
Other (please specify)

3 Additional comments

None

4 Please comment on the performance of other organisations that were involved in this visit

Everybody was very cooperative

Failure to submit a complete report may jeopardise future applications for support from the Royal Society.
Please note that receipt of this report will not normally be acknowledged.