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Highlights

- Distinct Flow Constraints
- Locations and Improvement
- Modified Pyrolysis Process
- Solar Energy and Determination

Discovering Thoughts, Inventing Future

VOLUME 13 ISSUE 11 VERSION 1.0

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Monitoring of Particulate Matter in Different Locations and Improvement of Indoor Air Quality in Rajshahi City of Bangladesh

By Md. Raqibul Haque, Shakil Ahmed & Md. Shamim Akhter
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Abstract- Clean rooms today are highly technological solutions with very high demands on the air cleanliness level. Using kerosene heater for cooking as well as cigarette smoking is important indoor source of fine and coarse particles. It is important to estimate the level of air cleanliness in the cases of new production or reconstruction of a clean room. The air cleanliness level in a clean room is dependent on the quality of the supply air, contamination sources and the design of the ventilation system. By making proper design of air conditioning and ventilation system, the air cleanliness level can be controlled. The number of particulate matter also depends on humidity and temperature in the room at different times. In this study, indoor and outdoor air quality has been measured by an optical particle counter and experimental studies have been carried out to make the indoor air free from particulate matter. Different methods have been prescribed to make the indoor air free from particulate pollution. The results obtained from this experiment can be helpful to take necessary steps to keep the indoor air cleaner.

Keywords: outdoor air; indoor air; air filtration; particulate matter (pm); room environment.

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MONITORINGOFPARTICULATEMATTERINDIFFERENTLOCATIONSANDIMPROVEMENTOFINDOORAIRQUALITYINRAJSHAHICITYOFBANGLADESH

Monitoring of Particulate Matter in Different Locations and Improvement of Indoor Air Quality in Rajshahi City of Bangladesh

Md. Raqibul Haque [α], Shakil Ahmed [σ] & Md. Shamim Akhter [ρ]

Abstract- Clean rooms today are highly technological solutions with very high demands on the air cleanliness level. Using kerosene heater for cooking as well as cigarette smoking is important indoor source of fine and coarse particles. It is important to estimate the level of air cleanliness in the cases of new production or reconstruction of a clean room. The air cleanliness level in a clean room is dependent on the quality of the supply air, contamination sources and the design of the ventilation system. By making proper design of air conditioning and ventilation system, the air cleanliness level can be controlled. The number of particulate matter also depends on humidity and temperature in the room at different times. In this study, indoor and outdoor air quality has been measured by an optical particle counter and experimental studies have been carried out to make the indoor air free from particulate matter. Different methods have been prescribed to make the indoor air free from particulate pollution. The results obtained from this experiment can be helpful to take necessary steps to keep the indoor air cleaner.

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I. Introduction

The Environmental Protection Agency (EPA) of USA lists indoor air quality among the top 5 risks to human health, probably because indoor air can be 2-5 times more polluted than outdoor air. While homeowners can't see the majority of indoor air contaminants, every cubic foot of air breathed carries a mixture of millions of microscopic particles such as pollen, mold spores and dust mite debris. In small concentrations, these particles and gasses may cause discomfort in the home. In significant concentrations, they can cause sickness as these are among the most troublesome triggers of such ailments as asthma and allergies.

Particulate matter is the reason of particle pollution and it is a complex mixture of extremely small particles and liquid droplets suspended in a gas, which is usually air. Particulate pollution made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals and soil or dust particles. These particles can be suspended in the air for long periods of time. Some particles are large or dark enough to be seen as soot or smoke. Others are so small that individually they can only be detected with an electron microscope. Normally they are classified as coarse particles equal or greater than 10 μm and fine particles are less than 2.5 μm. Particulate matter is primarily formed from chemical reactions in the atmosphere and through fuel combustion with insufficient oxygen e.g. motor vehicles, power generation, industrial facilities, residential fire places, wood stoves and agricultural burning. Most people spend most of their time indoors. The most recent nationwide study of time budgets (Robinson and Nelson, 1995), based on interviews with 9.386 respondents in 1993-1994, indicates that US residents spend 87.2%of their time indoors, 7.25 in or near a vehicle and only 5.65 outdoors. This paper deals with field studies of particles indoors and outdoors, concentrating particularly on large-scale surveys of homes and buildings. The observed indoor particle concentrations are presented, together with the contributions of these studies toward understanding important parameters such as air exchange rates, source emission rates and penetration factors.

The manner in which particles are formed determines the size and composition of particles. The four main mechanisms of particulate matter formation described below.

- Physical attrition
- Combustion particle burnout.
- Homogeneous nucleation and heterogeneous nucleation of vapor phase compounds in hot gas streams.
- Release of solids during the evaporation of solids containing droplets in hot gas streams.

II. Experimental Procedure

In this experiment, outdoor and indoor air qualities were measured. The experiments were carried out in four different locations in Rajshahi city to measure the outdoor air quality as well as in Higher Education Quality Enhancement Project (HEQEP) sub project CP-521 office room in Rajshahi University of Engineering and Technology (RUET), Rajshahi for indoor air quality. Rajshahi city is the headquarter of Rajshahi division and is situated in north-western region of Bangladesh at

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latitude 24° N and longitude 88° E. Its total area is 96.69 km^2 (37.33 sq. miles).

a) Measurement of Outdoor air quality

Measurement of particulate matter (PM) was done in four different locations in Rajshahi city. The factors considered, while selecting a location, are:

- the total number of people is living into the location.
- the environmental condition around in location that affects the generation of particulate matter.
- the number of vehicles passing through or near the location and
- the number of industries and factories in or around the locations.

On the basis of above factors the following locations in the city were selected:

- Alupotti crossing.
- RDA market.
- Bus Terminal.
- Kumar para.

b) Measurement of Indoor Air Quality

The Higher Education Quality Enhancement Project (HEQEP) sub project CP-521 office room in RUET, Rajshahi was selected to investigate particulate matter in the room. The particle concentration in a room depends on:

- ➢ Ventilation system.
- ➢ Number of doors and windows.
- ➢ Positioning of doors and windows.
- ➢ Length, width and height of the room.
- ➢ Use of water heater and cooler in the room.
- ➢ No. of air conditioner in the room.
- ➢ Penetration rate.
- ➢ Indoor air contaminants e.g., chemical, dust, bacteria, gases, vapors.
- ➢ Quality of outdoor air.

The number of particulate matter (PM) per unit of volume of the room was measured in both using and not using air conditioner. The room had only one ceiling fan and no ventilator. For measuring the concentration of particulate matter, the following conditions were taken for office room:

- ➢ Closing all doors and windows with ceiling fan on.
- ➢ Closing all doors and windows with ceiling fan off.
- ➢ Opening all doors and windows with ceiling fan on.
- ➢ Opening all doors and windows with ceiling fan off.
- ➢ Fitting filters to windows with windows open.

The Optical Particle Counter (OPC) SOLAIR-3100 of Lighthouse, UK, was used to measure the particle size distribution in both outdoor and indoor air. The specification of the OPC is given in APPENDIX I and the photographic view of the OPC is shown in Fig.1.

Figure 1 : Photographic view of Optical Particle Counter SOLAIR 3100

The device was operated with battery. The sampling probes were connected to the terminal. By pressing the power switch the device was turned on. Measuring mood, particle size, data storage, data printing, sampling time, frequency, delay and holding times were set up. The particle size range was 0.3 to 25 micrometers. Then sampling time was selected as 30 seconds for measurement. After that the interval was selected. It ranges from 1 sec to 24 hrs. We selected the interval between each measurement was one minute. Count per cubic meter was selected as measuring unit. Then the "OK" key was pressed to conform the setting and then pressed "SET" key to shift the measurement screen. After taking each data the machine was switched off. Once the measurement was finished, the data was dumped from the device. After getting all the data we made the device set at OFF.

III. Results and Discussion

Figs. 2 to 5 show the particle size distribution in different locations of Rajshahi city for outdoor air quality. From the figures it is clear that Maximum PM was found at Alupotti crossing and then the particle concentration decreases gradually in RDA market (2nd floor), Bus Terminal and Kumarpara. The total number of people staying in Alupotti crossing was maximum compared to the other locations. The number of vehicles, density of the shops and number of industries and factories around that location was also greater compared to RDA market, bus terminal and Kumarpara which made the difference of particle concentration of that locations.

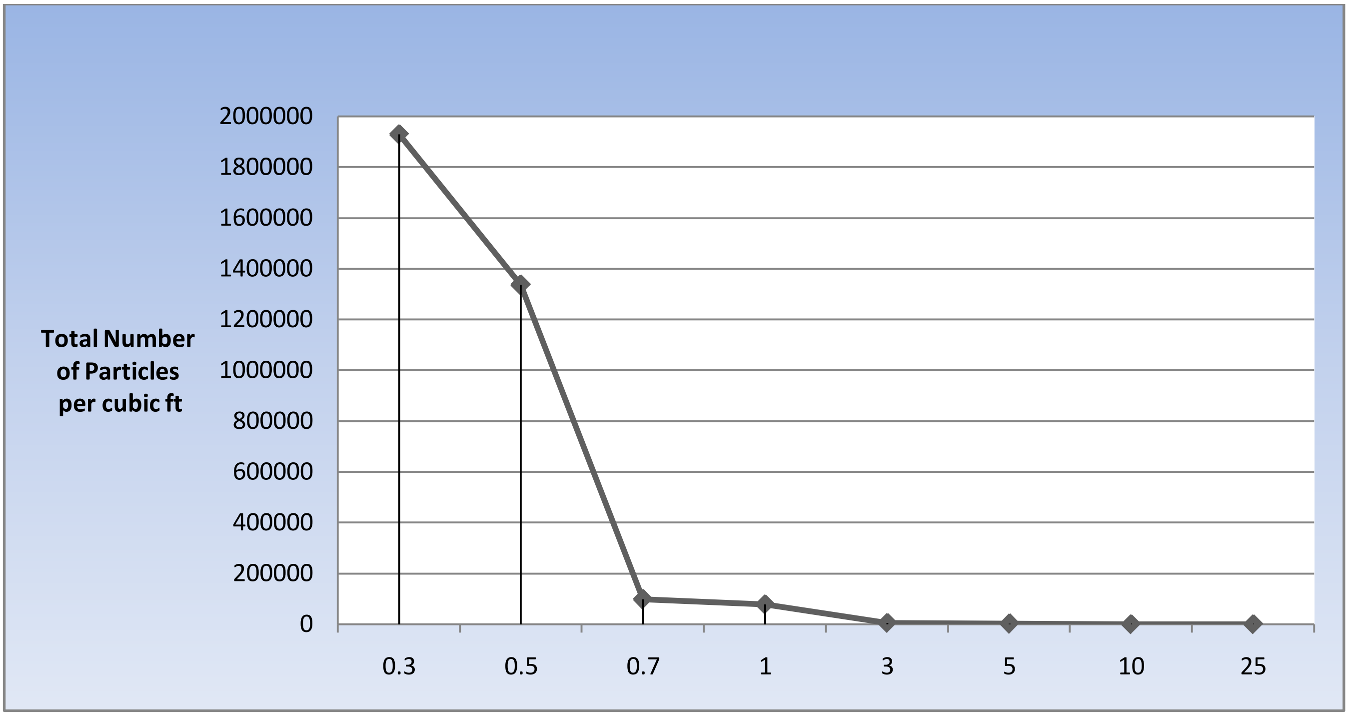

Figure 2 : Particle size distribution at Alupotti crossing at 12:10PM on 20-07-2013

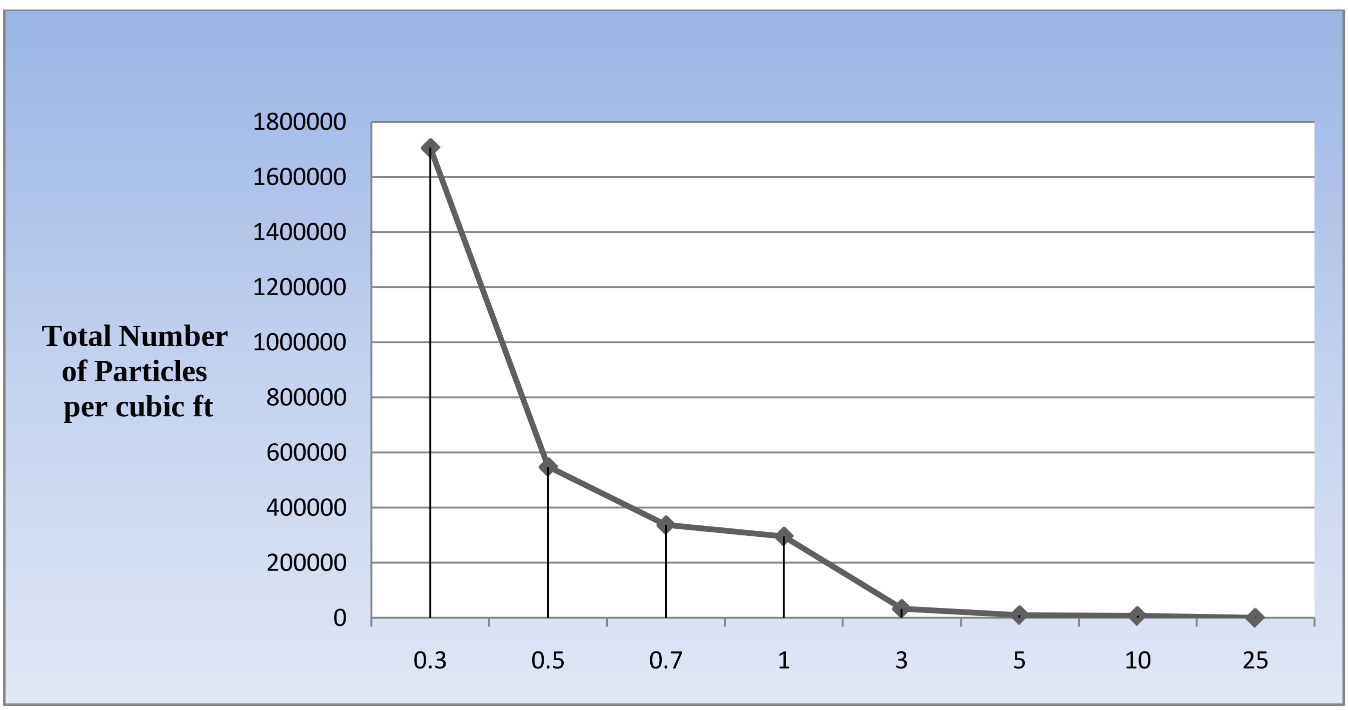

Figure 3 : Particle size distribution at RDA market at 12:20PM on 20-07-2013

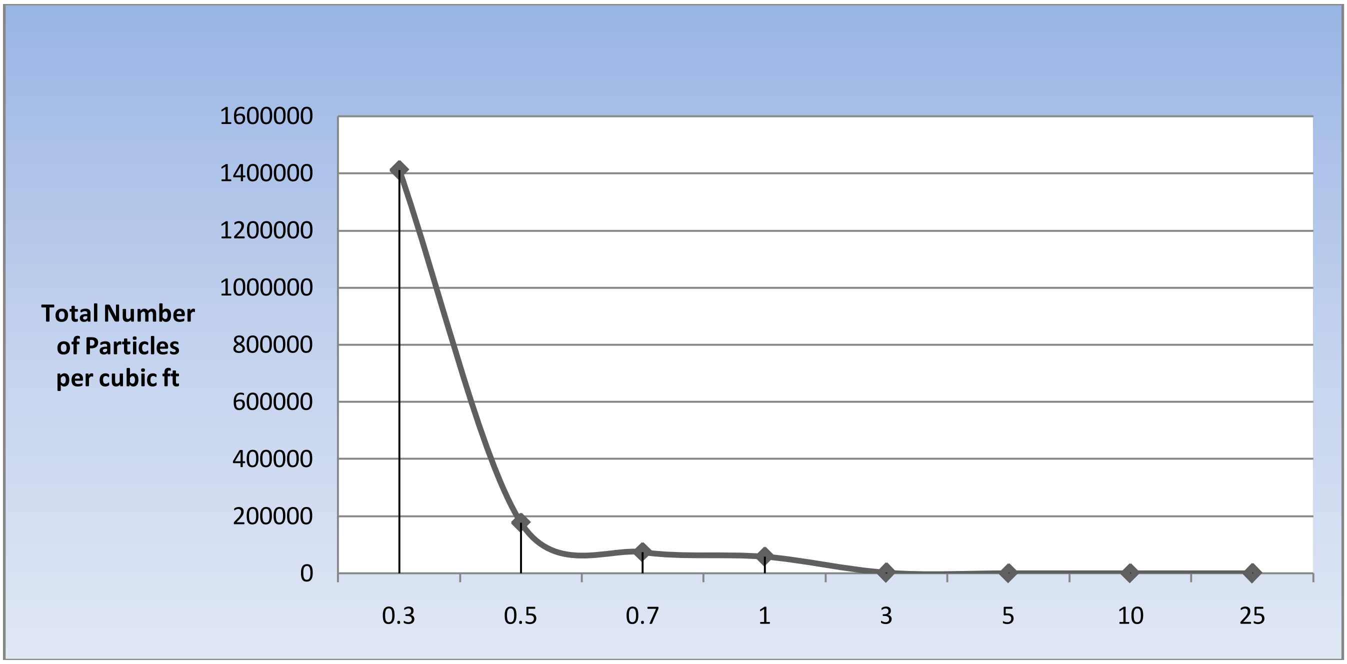

Figure 4 : Particle size distribution at Bus Terminal at 12:35PM on 20-07-2013

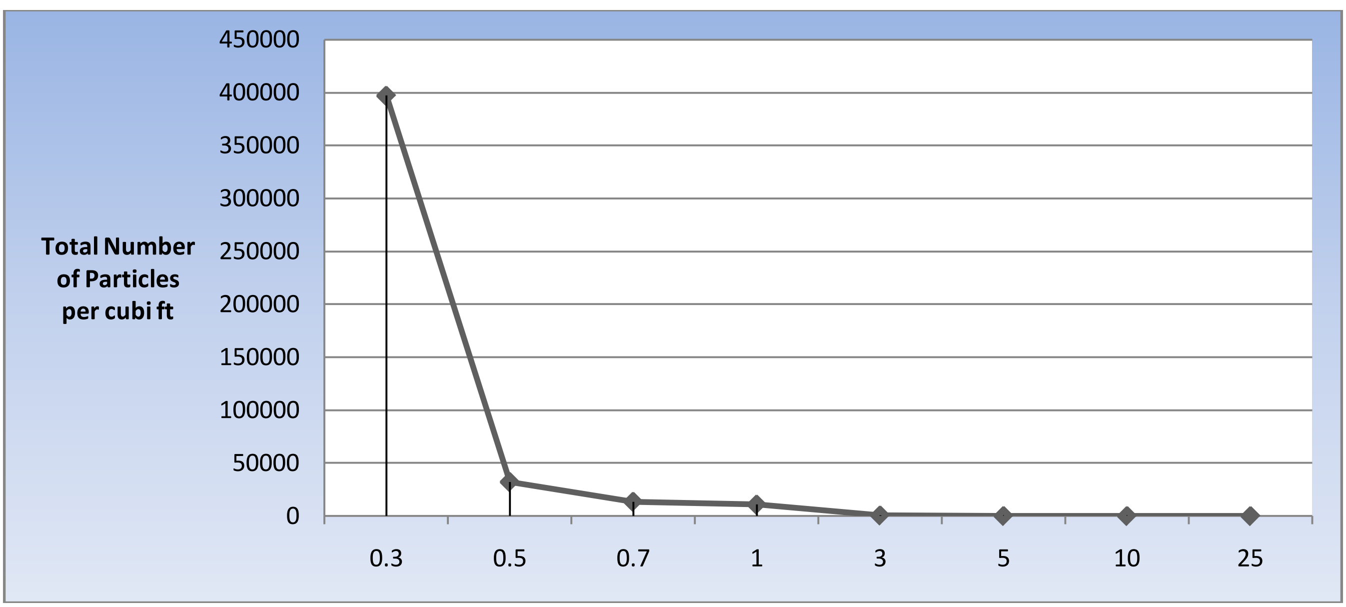

Figure 5 : Particle size distribution at Kumarpara at 01:10PM on 20-07-2013

The indoor air quality in HEQEP sub project CP-521 office room has been shown in Figs. 6 to 8. The figures show that the particle concentration was higher in non air conditioning room than air conditioning room. The particle concentration was also varied due to opening and closing the doors and windows with the ceiling fan on and off. The particulate matter was maximum when all the doors and windows were open and the ceiling fan was off. The particulate matter was reduced by fitting filters into the windows.

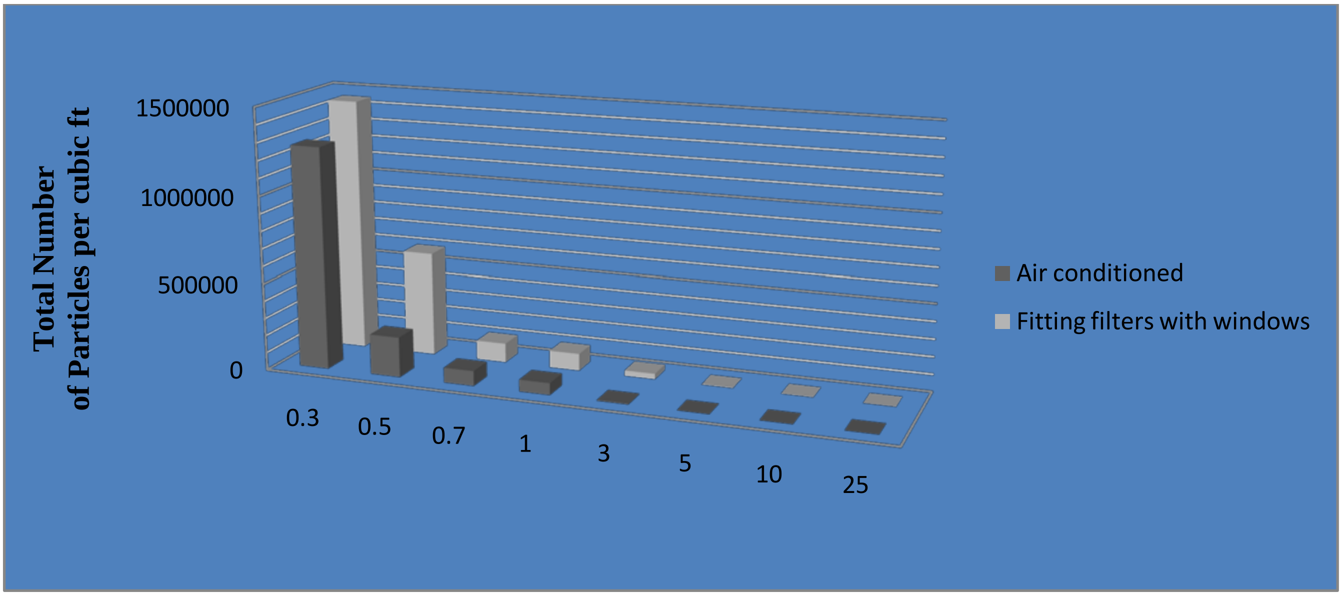

Figure 6 : Particle size distribution in HEQEP sub-project CP-521 office room at 11.20AM on 02-07-2013

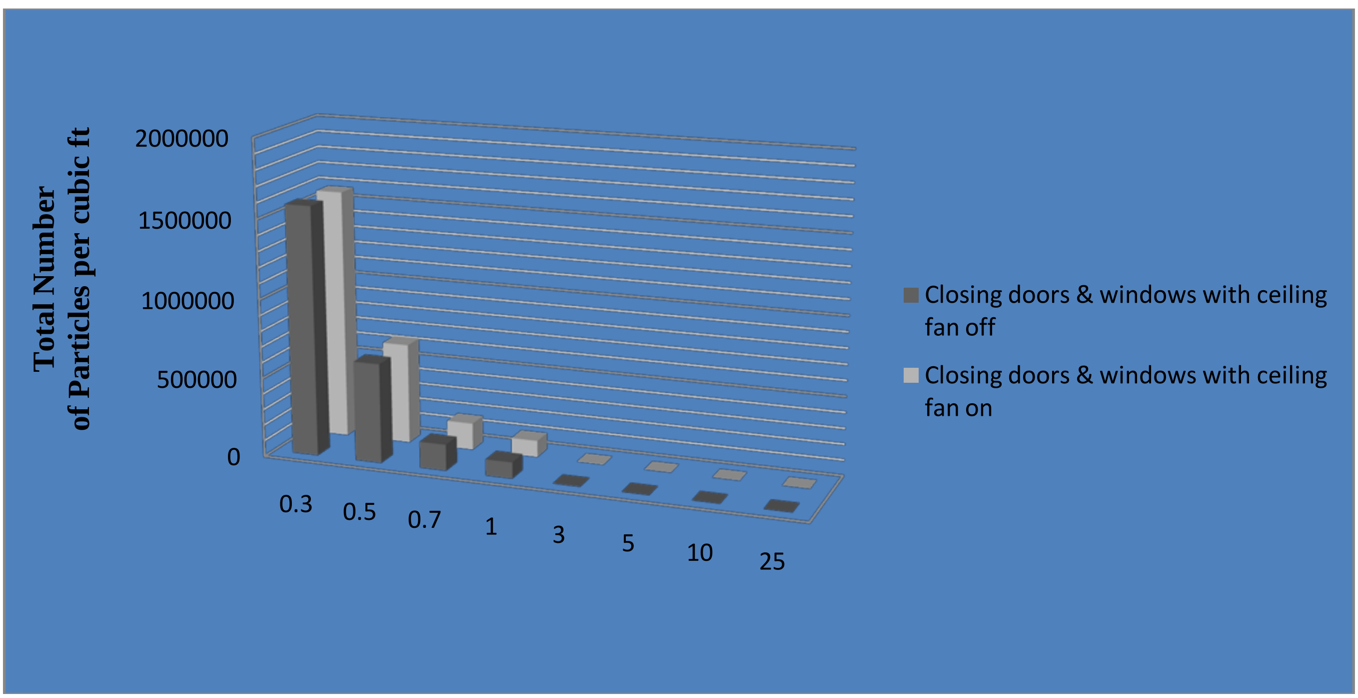

Figure 7 : Particle size distribution in HEQEP sub-project CP-521 office room (Non AC) at 11.40AM on 02-07-2013

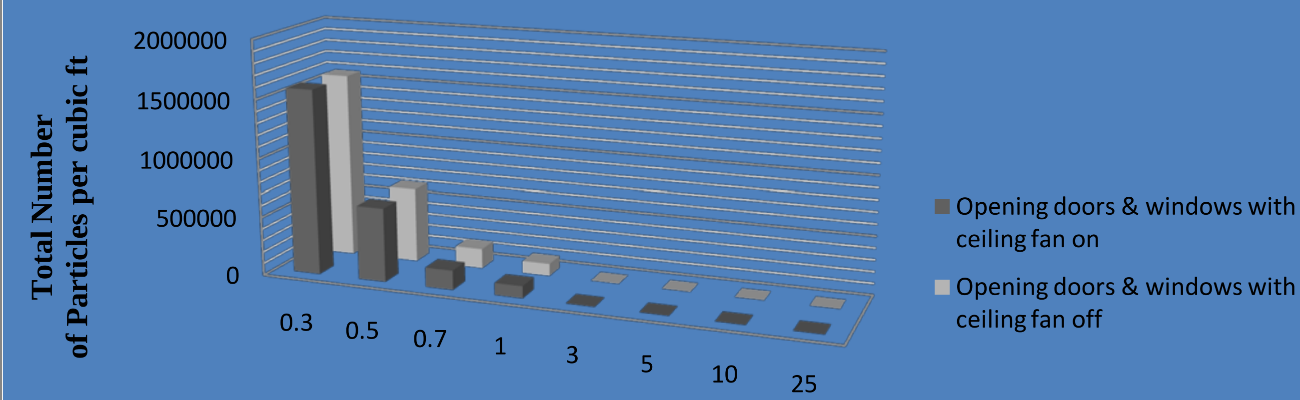

Fig. 8 Particle size distribution in HEQEP sub-project CP-521 office room (Non AC) at 11.55AM on 02-07-2013

Figure 8 : Particle size distribution in HEQEP sub-project CP-521 office room (Non AC) at 11.55AM on 02-07-2013

IV. CONCLUSIONS

From the experimental investigations, the following conclusions may be drawn:

- Out of the places in which data were taken, outdoor air quality is the dirtiest in Allupatti crossing in Rajshahi city
- Cleanest indoor air can be achieved by fitting sub-micron filters in doors and windows of the room.

V. ACKNOWLEDGEMENTS

The Authors wish to acknowledge with appreciation and pleasure the management of Higher Education Quality Enhancement Project (HEQEP) of University Grants Commission (UGC) for their co-operation and financial support extended to complete this research work, which has been carried out as a part of sub-project CP-521 in Mechanical Engineering Department, RUET, Rajshahi.

APPENDIX I

Specification of Airborne Particle Counter (OPC) SOLAIR-3100

Channel Thresholds	0.3,0.5,0.7,1.0,3.0,5.0,10.0,25.0 μm
Flow rate	1.0 CFM (28.3LPM)
Counting Efficiency	3100:50%@0.3 μm;100% for particles>0.45 μm(PER JIS) 5100:50%@0.5 μm;100% for particles>0.75 μm(per JIS)
Laser Source	Extreme Life Laser Diode
Zero Count Level	< 1 count/5 minutes (per ISO 21501-4)
Concentration	500,000 particles/ft3@5%Coincidence
Limits	Loss
Calibration	NIST Traceable
Count Modes	Concentration, manual, automatic, beep
Data Storage	Stores up to 3000 sample records of particle and environmental data, plus location and time
Communication Modes	Ethernet TCP/IP, RS485/Modbus. USB,USB Flash Drive
Supporting Software	LMS X Change Data Transfer Software Optional: LMS Express ,LMS Net
Printer	Thermal printer , optional , specify at time of order
Sample Output	Internally filtered to HEPA standard (>99.97%@0.3μm)
Vacuum Source	Internal clean pump , flow controlled
Power	100-240VAC,50-60Hz
Battery	Li-ion , removable and rechargeable
Operating temp/RH	50° F to 104° F(10°C to 40° C)/ 20% to 95% non -condensing

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Conjugate Cooling of a Protruding Heater in a Channel with Distinct Flow Constraints

By Thiago Antonini Alves & Carlos A.C. Altemani
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Abstract- The conjugate cooling of a single block heater mounted on a conductive wall of a parallel plates channel was investigated under distinct laminar airflow constraints: fixed flow rate, fixed channel flow pressure drop and fixed pumping power. The heater was cooled by direct forced convection to the airflow and by conduction through its contact with the channel wall. The investigation was performed for a twodimensional configuration with fixed channel geometry and variable heater height. At the channel entrance the flow velocity and temperature were uniform. The channel wall thickness was constant and its thermal conductivity ranged from 0 to 80 that of the air, while the heater thermal conductivity was equal to 500 that of the air. The conservation equations were solved numerically by the control volumes method with the SIMPLE algorithm. The results were expressed in dimensionless form, considering the three distinct flow constraints. For a fixed flow rate, the heater temperature always decreased as the heater height increased. For the other two flow constraints, there is a critical relative heater height which minimizes its thermal resistance to the airflow. The results also indicated that for a conductive substrate, the conduction from the heater to the substrate plate cannot be neglected in comparison to the direct convective cooling to the airflow.

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I. Introduction

The space available for electronic components mounted on circuit boards may sometimes be restricted and their cooling must be obtained by airflow with moderate velocities. Under these conditions, there may not be enough room to install a finned heat sink on the components with high heat dissipation rates. In this case, the thermal design may benefit from the conjugate forced convection-conduction cooling of a heated component.

Two extensive reviews of the literature on the conjugate forced convection-conduction heat transfer in electronic equipment were presented by Ortega [1] and Nakayama [2]. A modeling hierarchy for heat transfer study was adopted, involving both flush mounted heat sources (e.g., Ramadhyani et al. [3]) and protruding two-dimensional heat sources (e.g., Davalath and Bayazitoglu [4]). In this case, distinct investigations considered either periodically fully developed flow and heat transfer (e.g., Kim and Anand [5]) or a developing flow and heat transfer (e.g., Kim and Anand [6]). Nakayama and Park [7] presented an investigation of the conjugate heat transfer from a single three-dimensional heater mounted on the wall of a rectangular channel with a 16:1 aspect ratio. Their experimental measurements, considering air velocities in the range from 1 to 7 m/s, were employed to set the boundary conditions for a numerical analysis of the conduction in the duct wall. From their data they derived a correlation for the direct convective heat transfer from the heated block to the airflow, but they pointed out that it did not agree with the predictions of previous correlations from the literature. As a consequence, they indicated the need for more work to obtain a correlation of wider applicability, even for the direct heat transfer from the block. Nakamura and Igarashi [8] performed an experimental investigation to obtain a general correlation of the Nusselt number for a heated low-profile block placed in a rectangular duct. The correlation was shown to be applicable regardless of the configuration of the block and duct, expressed in terms of a modified Reynolds number, under conditions of laminar flow, a low profile block and a low blockage effect. Due to these restrictions, it seems that even the direct convective heat transfer from a single heated block may still be considered an open problem to further research. When it comes to more than one heater mounted on a wall, several investigations presented in the recent literature were related to the thermal optimization, in which the heaters distribution usually is an important parameter. Silva et al. [9] considered two analytical approaches to optimize the distribution of heat sources flush mounted on a wall cooled by forced convection. The results were validated by a numerical investigation to distribute heat sources inside a channel formed by parallel plates. It was concluded that the heat sources should be placed nonunifomly on the wall, with the smallest distance between them near the tip of the boundary layer. This migration of the heat sources towards the tip was dependent on the Reynolds number and the heat sources length. Icoz et al. [10] presented a design methodology for air and liquid cooling systems applied to a parallel plates channel with two identical heating elements. The effects of the Reynolds number, the separation distance and the protrusion heights on the heat transfer rates from the heat sources and the channel flow pressure drop were investigated. The concurrent use of simulation and experiment was adopted in order to improve the efficiency of design optimization. The results indicated that the optimal

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values of Reynolds number, heat source height and separation distance between the heaters depend on an objective function. For air cooling, it was shown that the spacing needed to optimize the heat transfer from the downstream heater is greater than that for the upstream heater. In addition, the optimal Reynolds values for a given protrusion height were observed to be greater for the upstream heat source than the downstream source. The thermal optimization may be subjected to constraints such as the maximum component temperature, flow pressure drop or pumping power. These constraints may however also be considered even for the thermal design of a single heated component on a parallel plates channel.

The present work is concerned with the conjugate cooling of a single heater mounted on the lower wall of a two-dimensional parallel plates channel, as indicated in Fig. 1, under laminar airflow conditions. The thermal contact with the lower wall (substrate plate) was considered perfect and the energy dissipation rate per unit depth of the heater was constant. The conjugate cooling was by direct forced convection from the heater surfaces in contact with the airflow and by conduction through its contact with the substrate plate. The effects of the relative heater height in the channel, of the airflow rate and of the substrate plate thermal conductivity were considered in the analysis performed. The results will be presented considering three distinct constraints for the airflow in the channel: a specified flow rate, a fixed pressure drop and a constant pumping power. Due to the conjugate nature of the heater cooling, a dimensionless global thermal resistance was defined and presented in the results. In spite of the two-dimensional restriction of the present analysis, the heat transfer enhancement promoted by the substrate conduction was clearly identified.

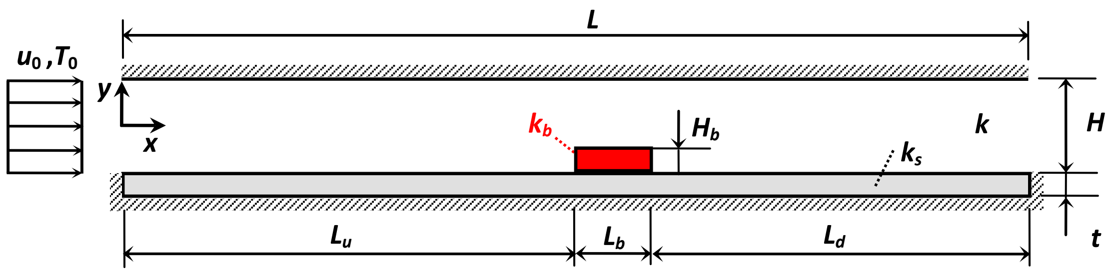

Figure 1 : Domain of the conjugate heat transfer problem

II. Analysis

a) Problem Formulation and Dimensionless Parameters

The present investigation was performed within the two-dimensional domain indicated in Fig. 1, comprising a parallel plates channel with a heater mounted on the lower wall. The channel had a fixed geometry, with height H and a total length $L = 20H$. The channel upstream length was $L_u = 10H$, the heater length $L_b = H$ and the downstream length $L_d = 9H$, as indicated in Fig. 1. The heater height H_b was a parameter of investigation, varying from zero (flush mounted heater) to a fraction ($H_b/H < 1$) of the channel height. This geometry was suggested by related works applied to the cooling of electronic components assembled on stacks of circuit boards, e.g., Davalath and Bayazitoglu [4], Nakayama [2], Zeng and Vafai [11] and Alves [12].

The heater cooling was provided by a laminar airflow with constant properties, under steady state conditions, with uniform velocity (u_0) and temperature (T_0) at the channel entrance. The corresponding Reynolds number was based on the channel hydraulic diameter,

$$Re = \frac{u_0 2H}{\upsilon} \qquad (1)$$

The channel lower wall had a thickness $t = (0.10\ H)$ and its thermal conductivity relative to the air, (k_s/k), was varied in the range from 0 to 80. Its upper surface was in contact with the channel flow and also supported the heater with perfect thermal contact. Its lower and lateral surfaces, as well as the channel upper surface, were adiabatic, as indicated in Fig. 1. The heater thermal conductivity relative to the air was $(k_b/k) = 500$. The heating was provided by a uniform volumetric heat generation rate within the heater, in such a way to always provide a heat generation rate equal to q'_b per unit depth normal to Fig. 1. When the heater was flush mounted, it generated a uniform heat flux along its length (L_b), such that the same heat transfer rate $q'_b = \left(q''_b\, L_b \right)$ was imposed.

The conservation equations of mass, momentum and energy for this combined entry length and conjugate heat transfer problem were expressed in dimensionless form. The dimensionless variables were, referred to Fig. 1, $X = x/(2H)$, $Y = y/(2H)$, $U = u/u_0$, $V = v/u_0$, $p^* = p/(\rho\ u_0^2)$, and $\theta = \left(T - T_0\right)k/q'_b$. A numerical solution procedure, to be described in the next section, employed the same form of the conservation equations in the solid and fluid regions of the domain presented in Fig. 1. In the solid regions, the artifice of very large local viscosity was used (i.e., a very small local Re), so that the resulting local velocities were negligible. The conservation equations in dimensionless form were

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \qquad (2)$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial p^*}{\partial X}+\frac{1}{Re}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \qquad (3)$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial p^*}{\partial Y}+\frac{1}{Re}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right) \qquad (4)$$

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1}{Re\,Pr}\frac{k^+}{C^+}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right)+S^* \qquad (5)$$

Besides the uniform velocity u_0 at the flow inlet, the outflow boundary was treated with negligible diffusion for both velocity components. Along the upper and lower surfaces of the domain, both velocity components were equal to zero. The flow temperature was uniform (T_0) at the channel inlet, while the upper and lower surfaces of the domain and both ends of the substrate plate were adiabatic. At the outflow boundary, the temperature profile was obtained considering negligible diffusion. The dimensionless volumetric source term S^* indicated in Eq. (5) was not negligible only in the solid region comprised by the heater, where it was uniform, expressed by

$$S^*=\left(Re\,Pr\,H_b^*L_b^*C^+\right)^{-1} \qquad (6)$$

In Eq. (5) k^+ and C^+ (6), k+ and C+ represent respectively the thermal conductivity and the unit thermal capacity (ρc) of each region relative to those of the air. The fluid Prandtl number is represented by *Pr* and the dimensionless heater height and length are respectively $H_b^* = (H_b/2H)$ and $L_b^* = (L_b/2H)$. The dimensionless volumetric source term S^* was always uniform in each investigated case, but it changed with the heater height and the fluid flow rate, as indicated in Eq. (6). The properties of the cooling fluid (air) were constant, taken from a table at 300 K (Kays and Crawford [13]) for the simulations performed.

The flow pressure drop $\left(\Delta p=\rho u_0^2\Delta p^*\right)$ across the channel was obtained from the average pressure distributions evaluated at the inlet and outlet channel boundaries. The flow pumping power (P'_W) was obtained by the product of the referred pressure drop and the corresponding channel volumetric flow rate. It was expressed in dimensionless form considering its ratio with the heat generation per unit heater length:

$$\frac{P'_W}{q'_b}=\left(\frac{\upsilon\Delta p}{q'_b}\right)\frac{Re}{2} \qquad (7)$$

The term in parenthesis on the right side of Eq. (7) represents a dimensionless pressure drop, which will be denoted by $\Delta p^+=\left(\upsilon\Delta p/q'_b\right)$. It is proportional to the pressure drop, since the fluid properties and the heat generation within the heater were constant. The left side of this equation represents a dimensionless pumping power, which will be denoted by $W_p^+=\left(P'_W/q'_b\right)$.

Since all the heat generation rate will ultimately be transferred to the airflow, the heater average surface temperature along its four edges, $\overline{T}_h$, was evaluated from the local distribution in order to define a dimensionless global thermal resistance per unit depth, as follows:

$$R'_t=\frac{k\left(\overline{T}_h-T_0\right)}{q'_b} \qquad (8)$$

This thermal resistance corresponds to the heater dimensionless average surface temperature, i.e., $R'_t=\overline{\theta}_h$.

b) *Numerical Solution Procedure*

The stated conservation equations were solved considering the conjugate domain indicated in Fig. 1, comprising the substrate plate, the heater and the flow regions. The control volumes method (Patankar [14]) was employed with the *SIMPLE* algorithm in order to obtain the flow field. A very small *Re* was imposed in all the control volumes in the solid regions, so that the resulting velocities were negligible in the substrate plate and heater. At the solid-fluid interfaces, the diffusion coefficients were evaluated by the harmonic mean in order to handle the abrupt changes of the solid to fluid properties. The mentioned boundary conditions for the flow and for the temperature distributions were imposed at the four boundaries of the domain presented in Fig. 1.

The results were obtained with a non-uniform grid deployed on the solution domain, comprising 348 control volumes in x -direction and 34 control volumes in the y-direction. It should be kept in mind that the channel aspect ratio was fixed, with $(L/H) = 20$, and that the lower wall thickness was related to the channel height as $(t/H) = 0.10$. In the x-direction, the grid was most refined over the heater length L_b, which contained 80 uniformly distributed control volumes. Along the upstream length L_u, 194 control volumes were uniformly deployed, and 74 others were distributed along the downstream length L_d. Along the y -direction, the grid was finer near the solid-fluid interfaces due to larger gradients of the dependent variables in these regions.

Several grids were tested before the final selection to obtain the numerical results. Most of the tests involving grid refinement were performed with *Re* = 1260. The number of grid points was increased until further grid refinement practically did not change the obtained results. The Richardson extrapolation technique (De Vahl Davis [15]) was employed for a particular case, indicating that the numerical error associated with the grid spacing was of second order. It was also verified that in the conductive substrate plate a uniform grid with 4 control volumes along its thickness was enough to obtain results independent of further grid refinement.

The discretization equations and their boundary conditions were solved by an iterative process based on the line-by-line method described by Patankar [14]. The solution was achieved when the absolute changes of the primitive variables in several locations were smaller than 10^{-5} between two consecutive iterations, while the global mass conservation in the domain was satisfied in all iterations. The numerical results were obtained in a microcomputer (Intel® Core™ 2 Quad Q6600 processor 2.4GHz and 4GB RAM), in about 15 minutes for a typical solution considering a conductive substrate.

III. Results and Discussion

a) Fixed Mass Flow Rate

The condition of fixed mass flow rate through the channel was specified in dimensionless form by a constant Reynolds number (*Re*). Five values of *Re* in the range from 630 to 1890 were selected in the laminar regime to present the results. They correspond, for a channel height H = 0.01 m, to u_0 in the range from 0.5 m/s to 1.5 m/s. The results will be presented in terms of a dimensionless heater height defined by $H_b^+ =$ (H_b/H), because it was felt more intuitive than $(H_b/2H)$. The dimensionless pressure drop $\Delta p^+ = \upsilon \Delta p / q_b'$ in the channel is presented in Fig. 2 as a function of the dimensionless heater height H_b^+, for the distinct values of *Re*. It shows that Δp^+ increases with both *Re* and H_b^+, due respectively to larger shear stress and an increased obstruction of the channel cross section. The heater height H_b^+ in this figure is limited to 0.40 in order to keep the flow recirculation downstream of the heater within the channel.

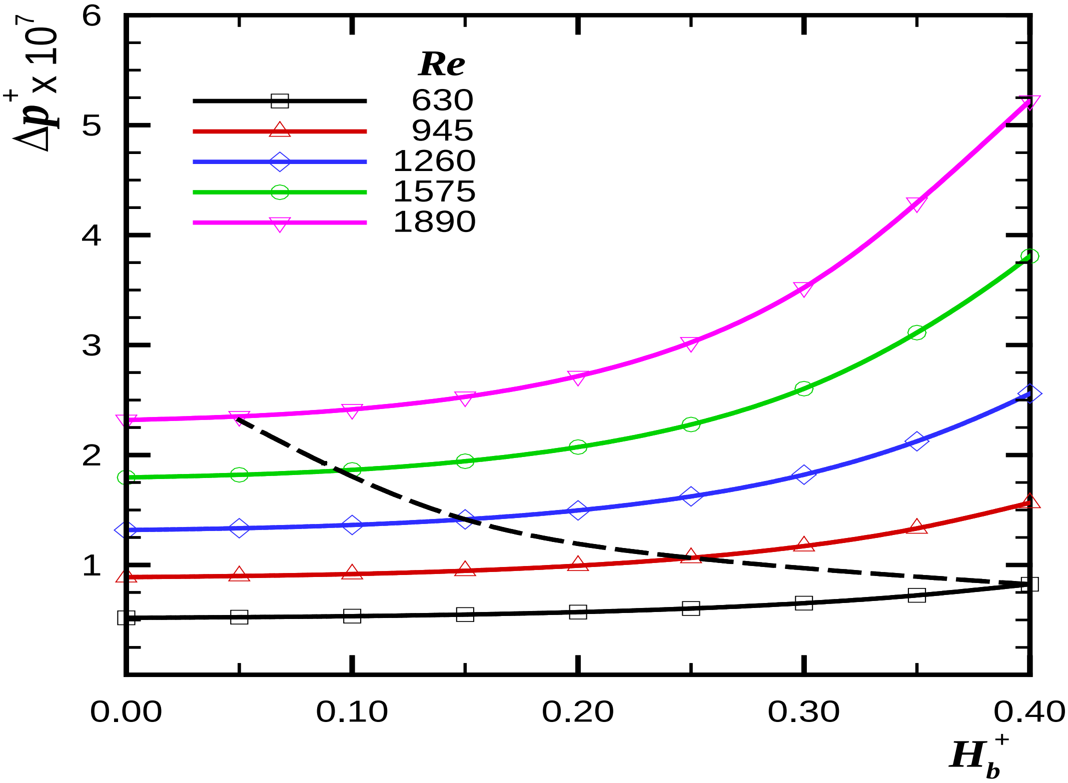

Figure 2 : Flow pressure drop for fixed flow rate

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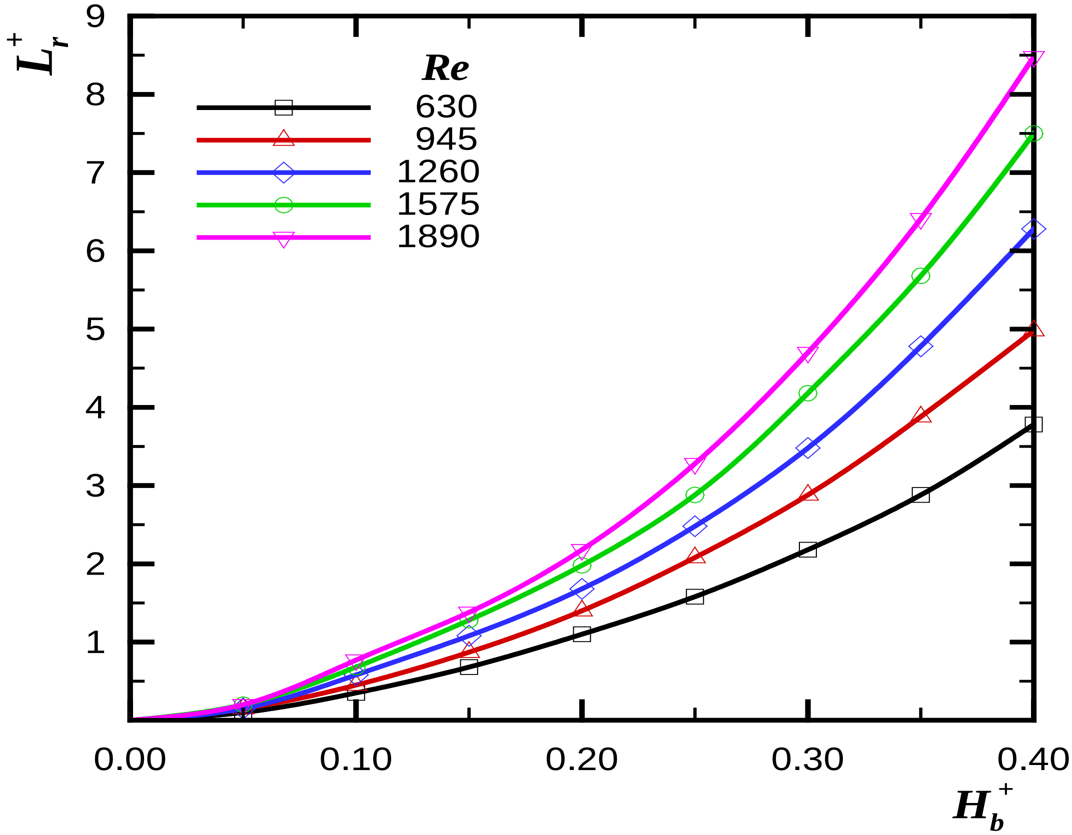

Figure 3 : Flow recirculation length downstream of the heater

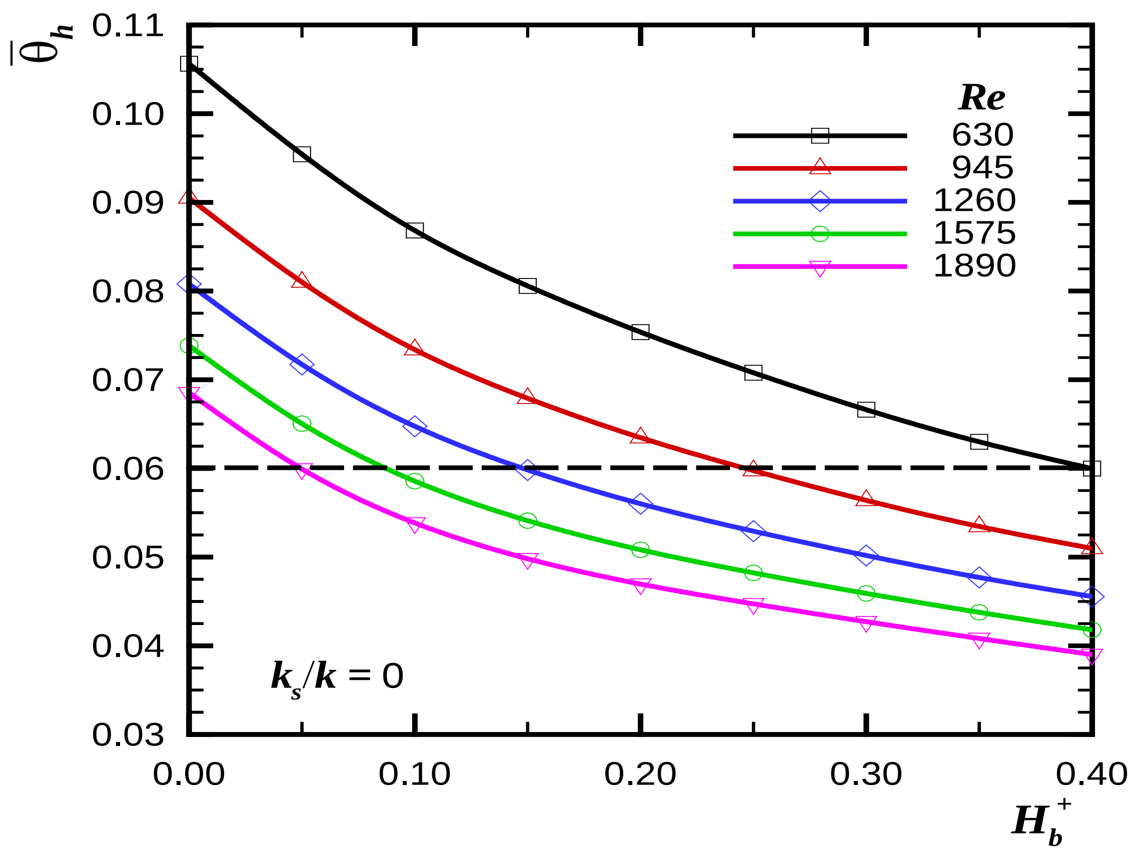

Figure 4 : Heater average temperature – fixed flow rate and $(k_s/k) = 0$

A conductive substrate wall provides a conduction heat spreader for the heater at their common interface. Thus, the heater cooling is provided by a conjugate forced convection-conduction heat transfer. The results for the heater average temperature $\overline{\theta}_h$, considering a substrate to air thermal conductivity ratio (k_s/k) = 80, are presented in Fig. 6. The effects of *Re* and the relative height H_b^+ are similar to those for the adiabatic substrate, i.e., the temperature $\overline{\theta}_h$ decreases when these parameters increase. Due however to the conjugate heat transfer, the temperature profiles in Fig. 6 are lower than those for the adiabatic substrate, as shown in Fig. 5. Considering the same heater temperature limit $\overline{\theta}_{h,max} = 0.06$ adopted for the adiabatic substrate, Fig. 6 shows that this thermal requirement would be satisfied now under any of the investigated conditions. This result indicates the remarkable contribution to thermal control due to conduction in the substrate. In this case, the flush mounted heater with the smallest airflow rate would require the minimum pumping power and pressure drop.

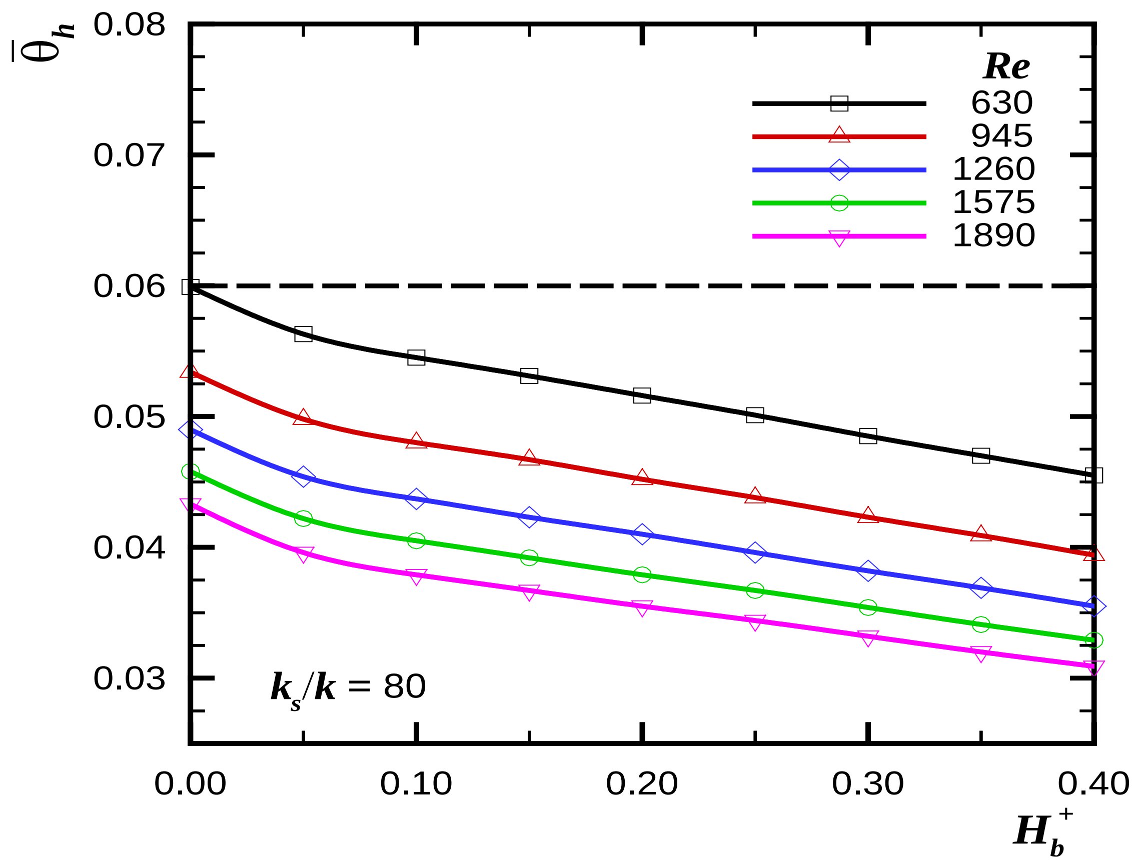

Figure 5 : Heater average temperature – fixed flow rate and (k_s/k) = 80

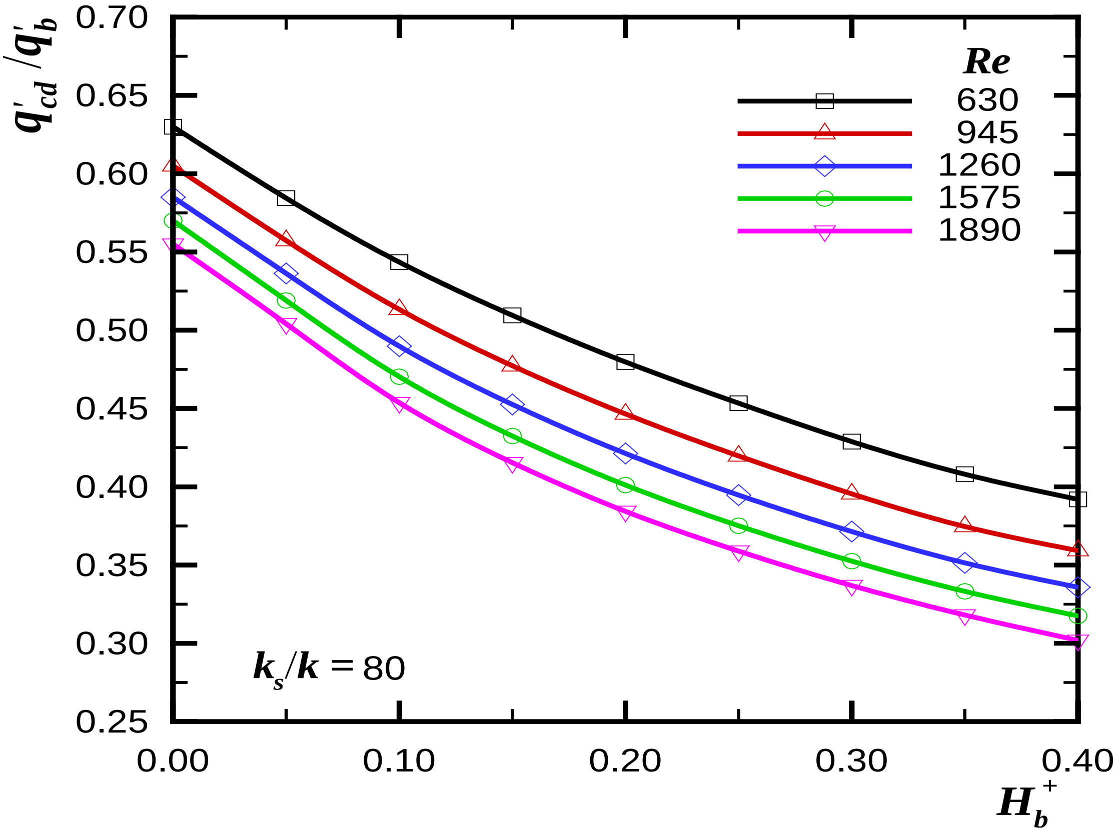

Figure 6 : Fraction of heat conduction through the substrate plate – (k_s/k) = 80

The heater conduction loss through the substrate relative to the total heat generation (q'_{cd}/q'_b) presents a trend similar to that of $\bar{\theta}_h$ with respect to *Re* and H_b^+, as shown in Fig. 6 for (k_s/k) = 80. These results also indicate that the conductive and the convective losses are of the same order and neither can be neglected. The channel flow pressure drop and the required pumping power for the conductive substrate are the same as those for the adiabatic substrate, since the flow properties are constant. An increase of the substrate thermal conductivity (k_s/k) decreases the heater average temperature $\bar{\theta}_h$, as presented in Fig. 7 for the smallest *Re* (the largest conduction contribution). This figure also shows that the minimum heater height H_b^+ needed to keep it below the temperature limit ($\bar{\theta}_{h,max} = 0.06$) decreases as (k_s/k) increases. Thus, for (k_s/k) = 0, a height H_b^+ = 0.40 is necessary, but for (k_s/k) = 80, the heater may be flush mounted on the substrate plate.

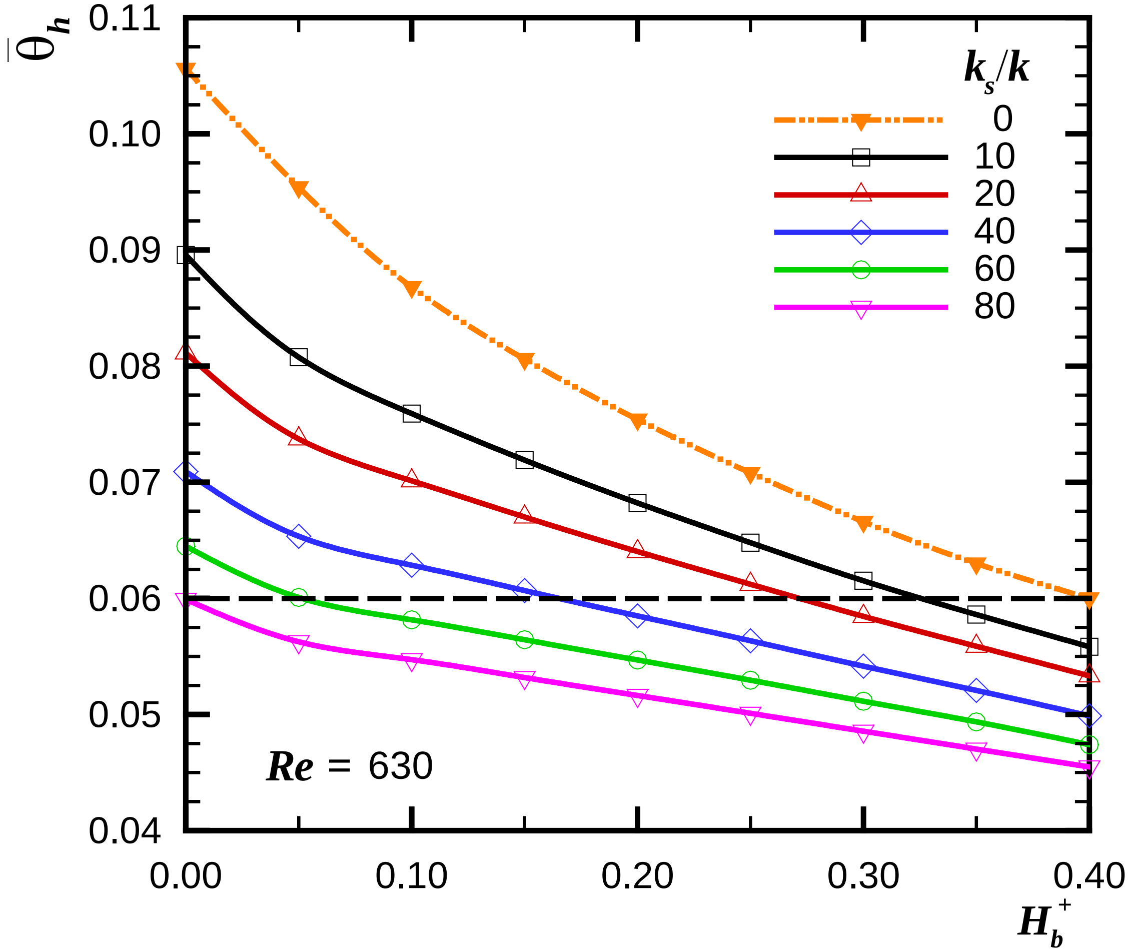

Figure 7 : Effect of the substrate thermal conductivity on $\bar{\theta}_h$ – *Re* = 630

- ***Fixed Pressure Drop***

The results obtained under the constraint of a fixed pressure drop will be considered now. Five values of Δp^+ were selected so that the flow remained in the laminar regime. As shown in Fig. 8, for any heater height H_b^+ the flow rate (*Re*) increases with the pressure drop Δp^+, but for a fixed Δp^+ it decreases as the heater height H_b^+ increases, due to flow obstruction. The pumping power W_p^+ for a fixed Δp^+ is proportional to the flow rate, so that it is similar to the trends observed in Fig. 8 for the channel flow rate.

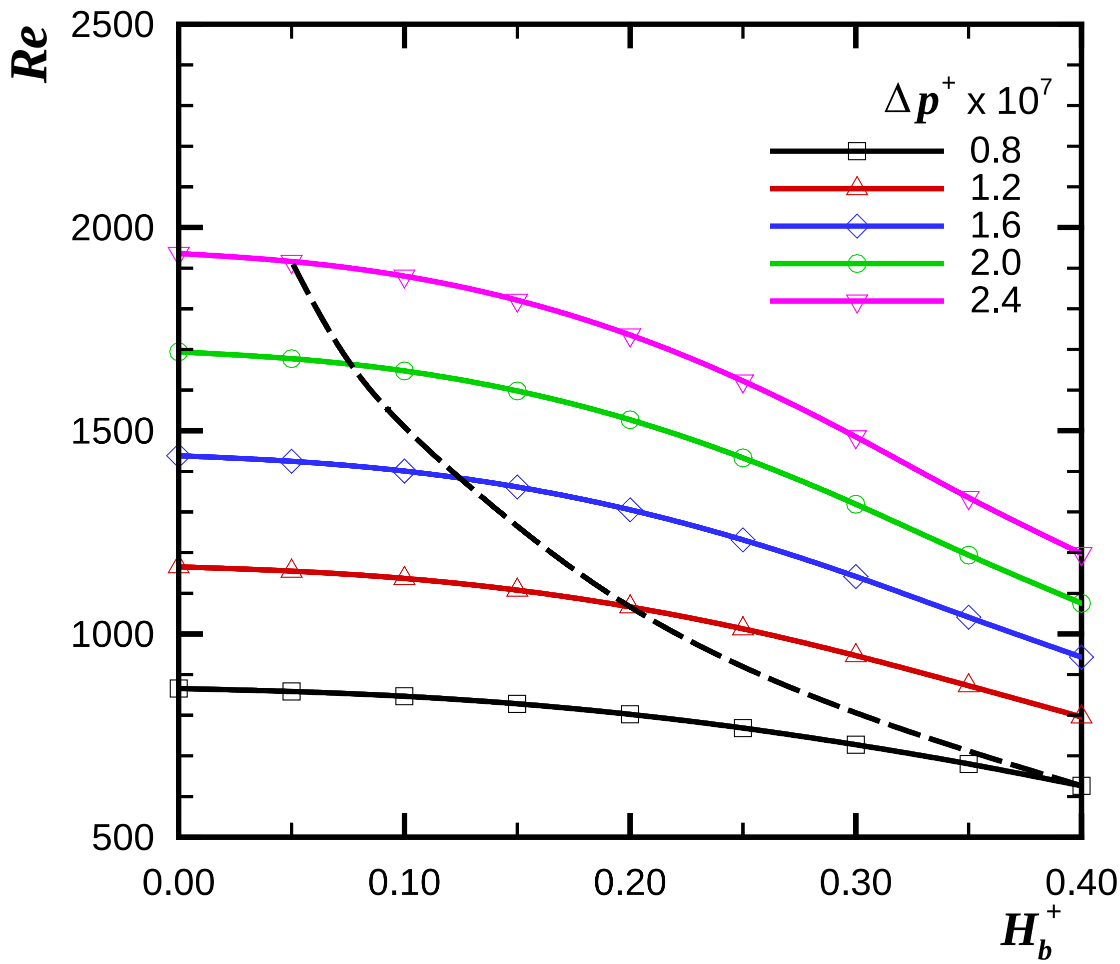

Figure 8 : Flow rate for fixed pressure drop

For an adiabatic substrate and the flow driven by a fixed pressure drop, the heater average temperature $\overline{\theta}_h$ is presented in Fig. 9, showing that within the investigated ranges of H_b^+ and *Re*, the temperature $\overline{\theta}_h$ decreases as the heater height increases. This figure also shows that for any heater height, the heater temperature decreases with the pressure drop due to larger channel flow rate. Considering again $\overline{\theta}_{h,max} = 0.06$, then the proper operating conditions are indicated by the region below the dashed line in Fig. 9. It shows that as the available pressure drop Δp^+ decreases, the minimum heater height must increase to provide a larger heat transfer area. The same dashed line is also indicated in Fig. 8, showing explicitly that as the minimum heater height increases, the channel mass flow rate for fixed pressure drop also decreases.

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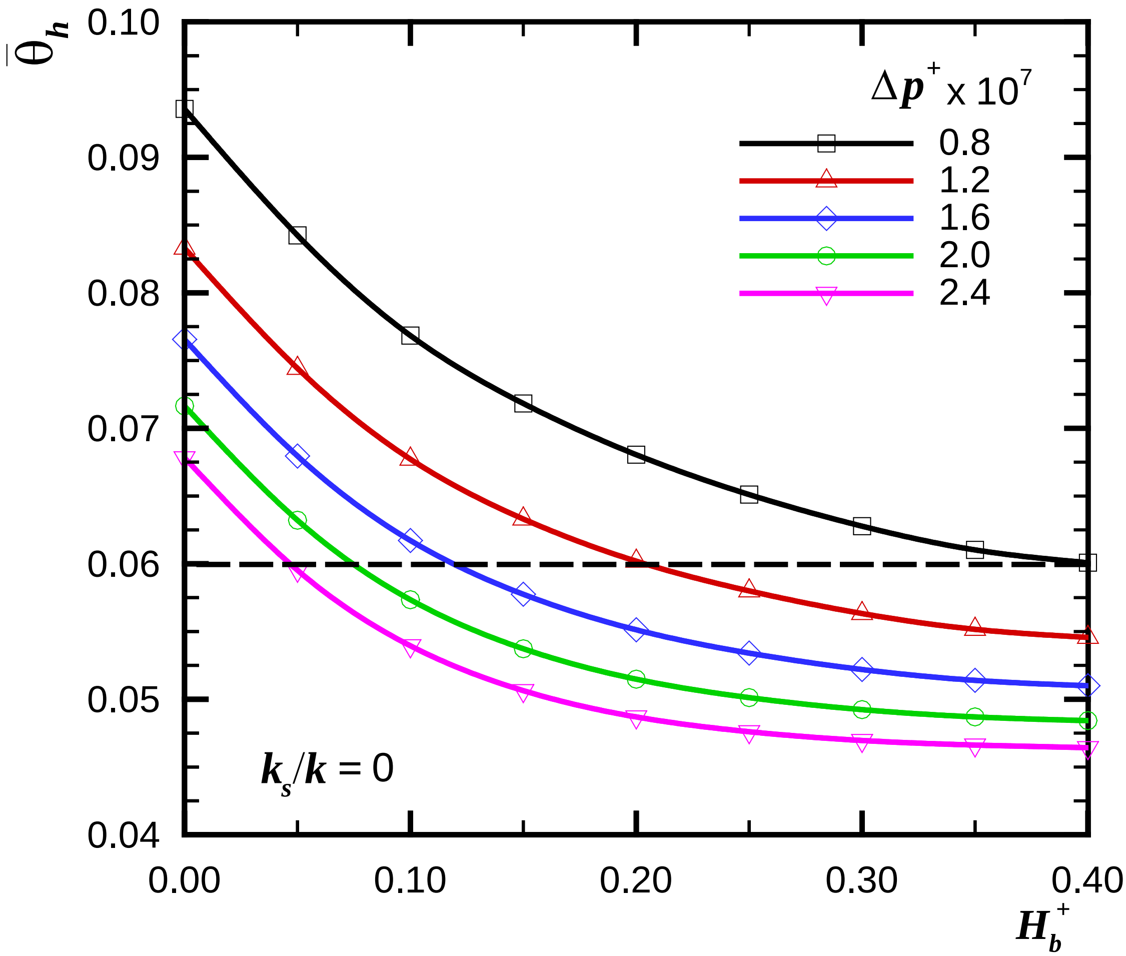

Figure 9 : Heater average temperature - fixed pressure drop and $(k_s/k) = 0$

When Δp^+ is fixed and the heater height increases, there are two opposing trends which determine the heater average temperature $\bar{\theta}_h$. One is a temperature decrease due to the increased heater area, and the other is just the opposite, a temperature increase due to the corresponding channel obstruction and flow rate decrease. The result of these opposite trends for $(k_s/k) = 0$ and $\Delta p^+ = 0.8\ 10^{-7}$ is presented in Fig. 10, showing that the heater attains a minimum average temperature $\bar{\theta}_h$ for $H_b^+ \cong 0.70$. As observed in this figure, for higher H_b^+, the channel obstruction causes a steep increase in $\bar{\theta}_h$.

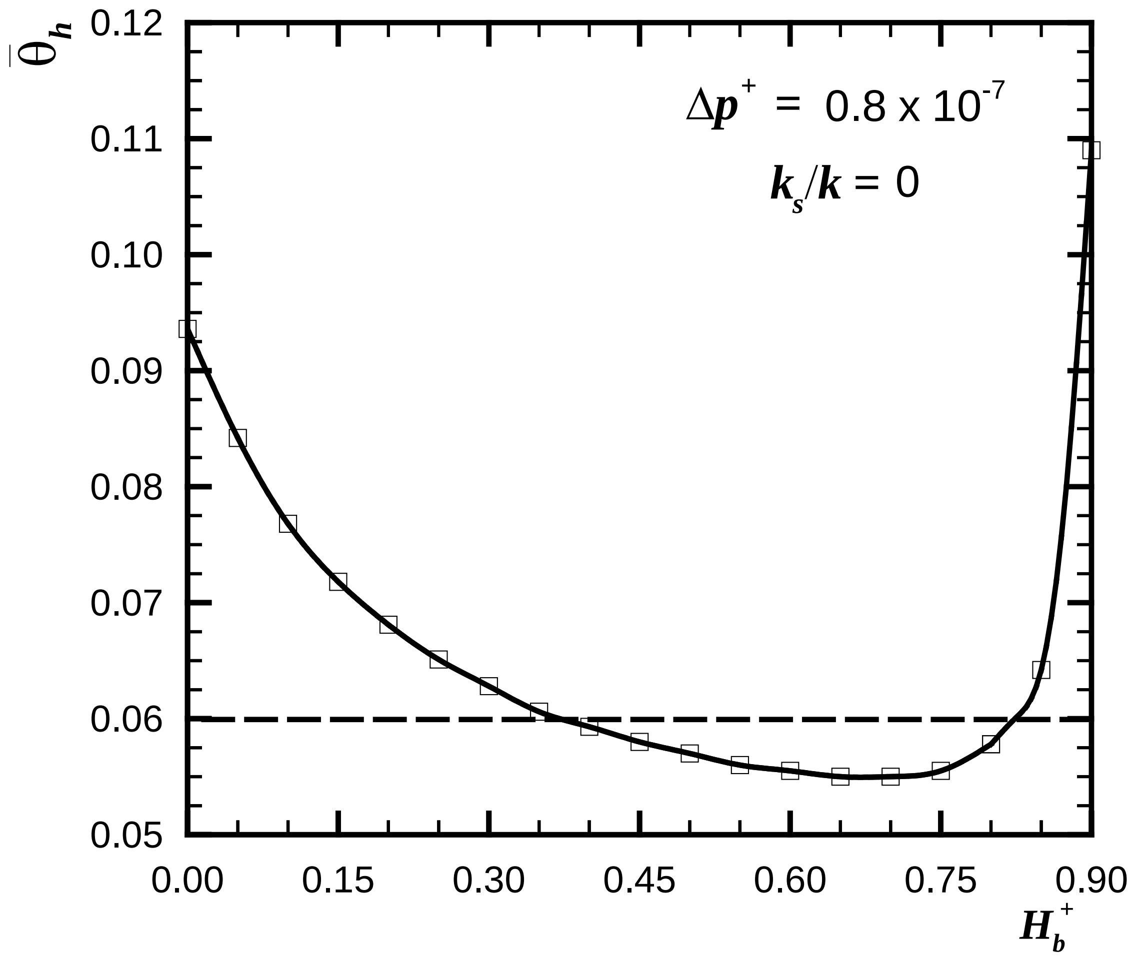

Figure 10 : Heater height for minimum temperature - fixed pressure drop and $(k_s/k) = 0$

The heater average temperature $\bar{\theta}_h$ for a conductive substrate with $(k_s/k) = 80$ is presented in Fig. 11 for the same fixed pressure drops Δp^+ used in Fig. 9. The trends are similar in both figures, but for the conductive substrate, due to the conjugate cooling, there is a substantial heater temperature decrease and a smaller relative change with the heater height H_b^+. Due to the conjugate cooling, the heater average temperature in Fig. 11 is below the considered limit of $\bar{\theta}_{h,max} = 0.06$ in all the investigated operating conditions.

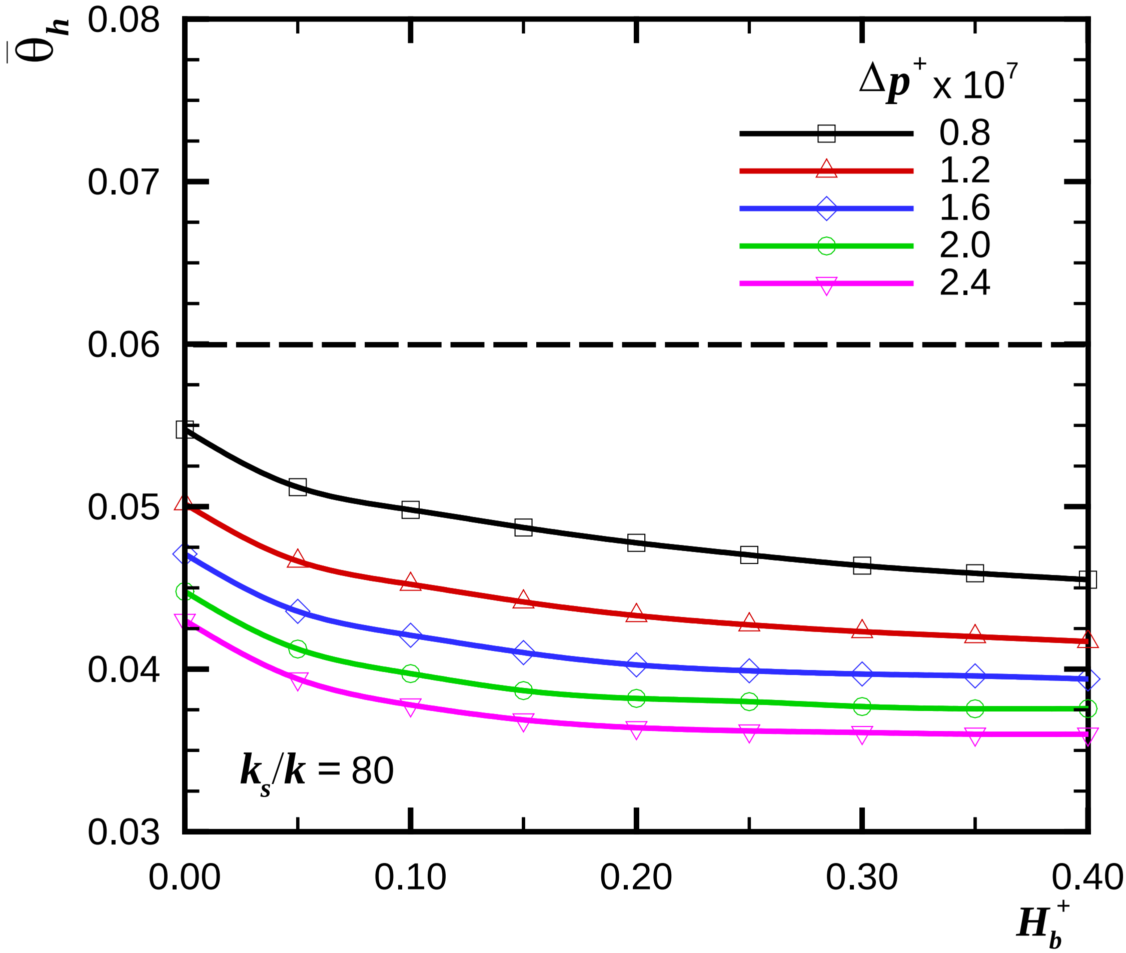

Figure 11 : Heater average temperature – fixed pressure drop and $(k_s/k) = 80$

- *Fixed Pumping Power*

When the channel flow is driven by a fixed pumping power, the product of the channel volumetric flow rate and the corresponding channel flow pressure drop remains constant. Thus, their change with the heater height must be opposite to each other. The results presented in Fig. 12 show the channel flow pressure drop Δp^+ for five distinct values of the dimensionless pumping power W_p^+, selected so that the resulting channel Re remained in the laminar regime. They show that for a fixed pumping power the pressure drop Δp^+ increases with the heater height and that for a given heater height it increases with the pumping power. Correspondingly, as mentioned, the channel flow rate for fixed pumping power must present an equivalent decrease with the heater height.

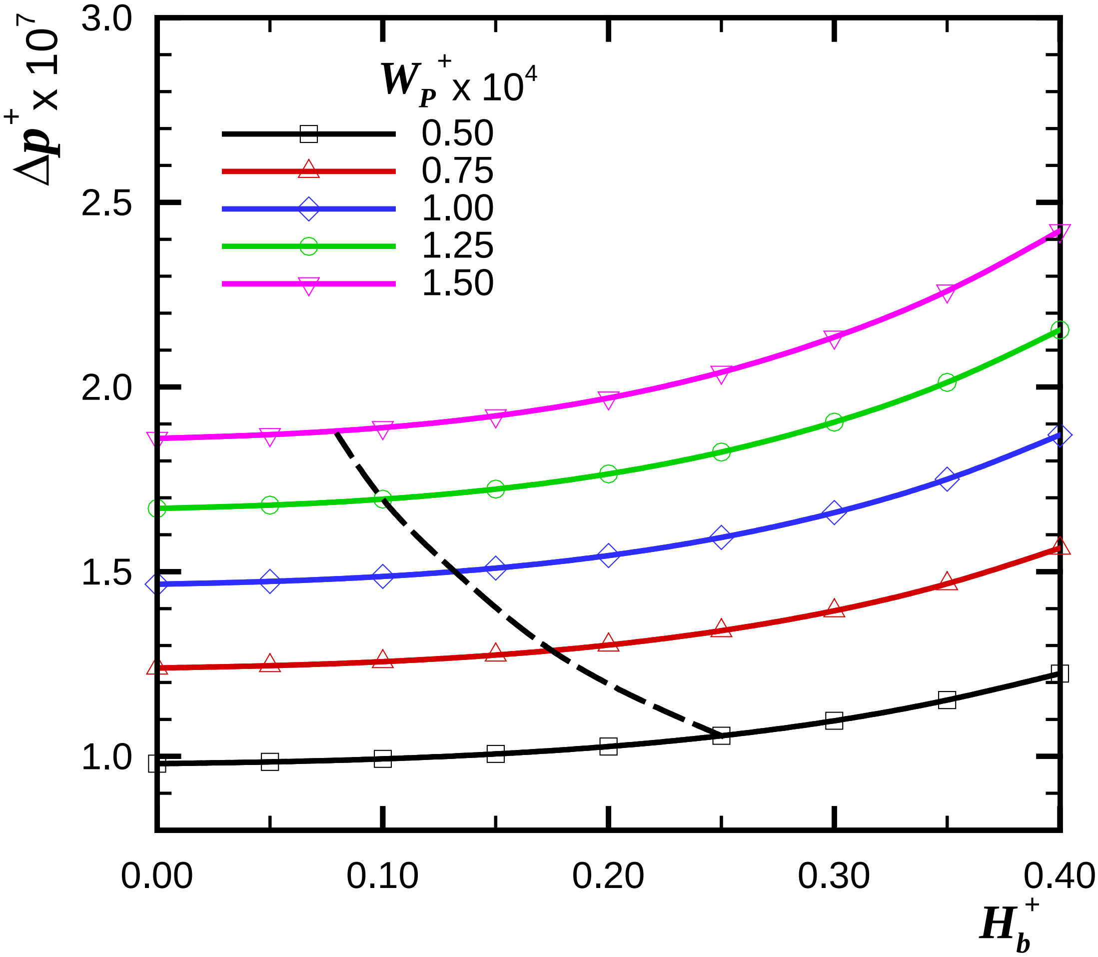

Figure 12 : Pressure drop for fixed pumping power

For an adiabatic substrate and the flow driven by fixed pumping power, Fig. 13 shows that the heater temperature $\bar{\theta}_h$ decreases as the heater height increases, while for a fixed heater height the temperature decreases with an increase of the pumping power, due respectively to an increased heat transfer area and a larger channel flow rate. Under fixed pumping power, an increase of the heater height H_b^+ increases the heat transfer area but reduces the channel flow rate. These two effects cause opposite trends on the heater temperature $\bar{\theta}_h$, so that this constraint also must present a heater height H_b^+ with minimum heater temperature. The curves drawn in Fig. 13 do not show the minimum because they were limited to $H_b^+ = 0.40$ due to the mentioned length of the flow recirculation zone downstream of the heater. The same heater temperature limit $\bar{\theta}_{h,max} = 0.06$ is presented as the dashed line in Fig. 13, indicating that the minimum needed heater height increases as the pumping power decreases. This dashed line is also presented in Fig. 12, indicating that when the fixed pumping power decreases, the channel flow rate and pressure drop decrease together and a taller heater is required to keep its average temperature below the maximum value.

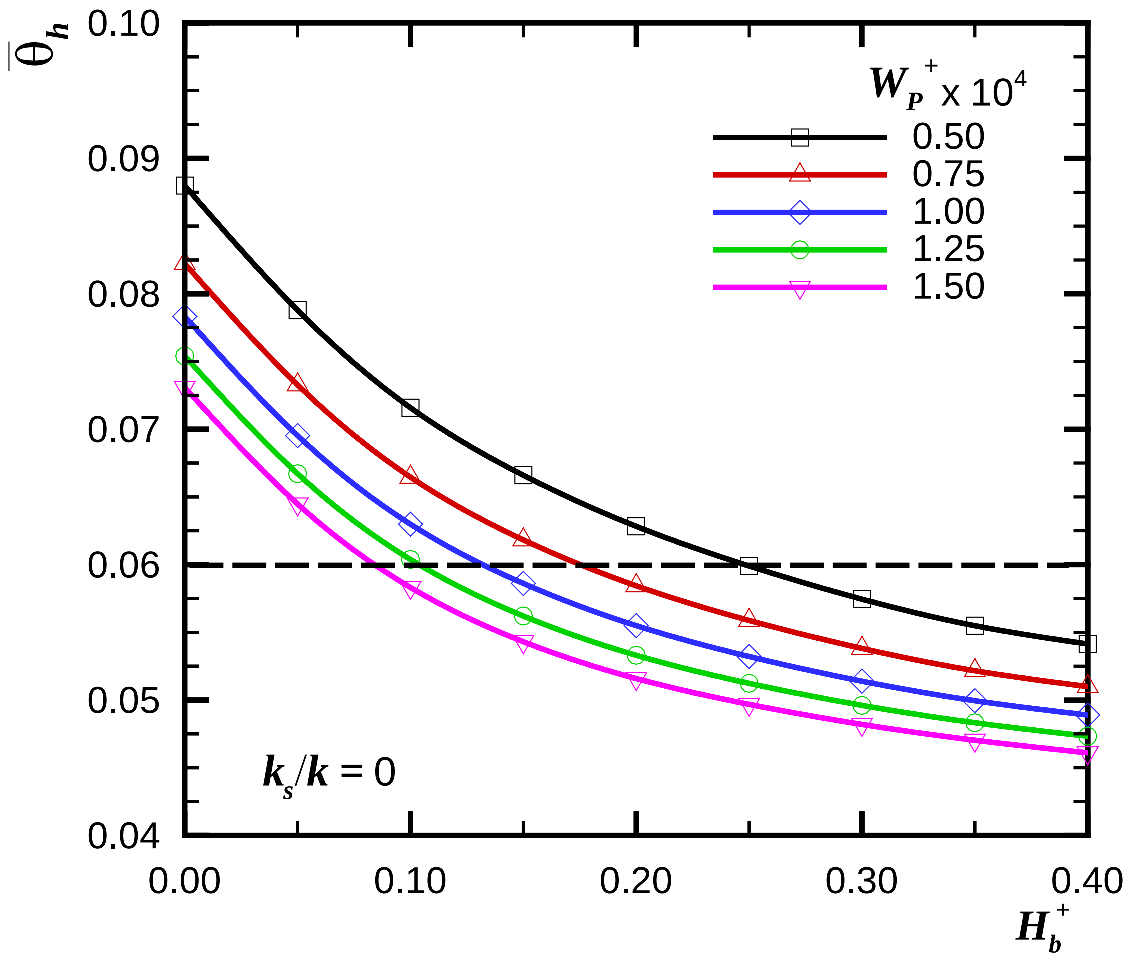

Figure 13 : Heater average temperature – fixed pumping power and $(k_s/k) = 0$

For a conductive substrate with $(k_s/k) = 80$, the resulting heater average temperature $\overline{\theta}_h$ is presented in Fig. 14 for fixed values of the dimensionless pumping power W_p^+. The trends are similar to those presented in Fig. 13, but this figure gives more evidence to the potential for the heat transfer enhancement obtained with the conductive substrate. The heater average temperature $\overline{\theta}_h$ in all the tested operating conditions was below the dashed line $\overline{\theta}_{h,max} = 0.06$. Considering for example the lower range of H_b^+ in Fig. 14, the values of $\overline{\theta}_h$ (or the heater global thermal resistance) are about 60 % of those for the adiabatic substrate (indicated in Fig. 13).

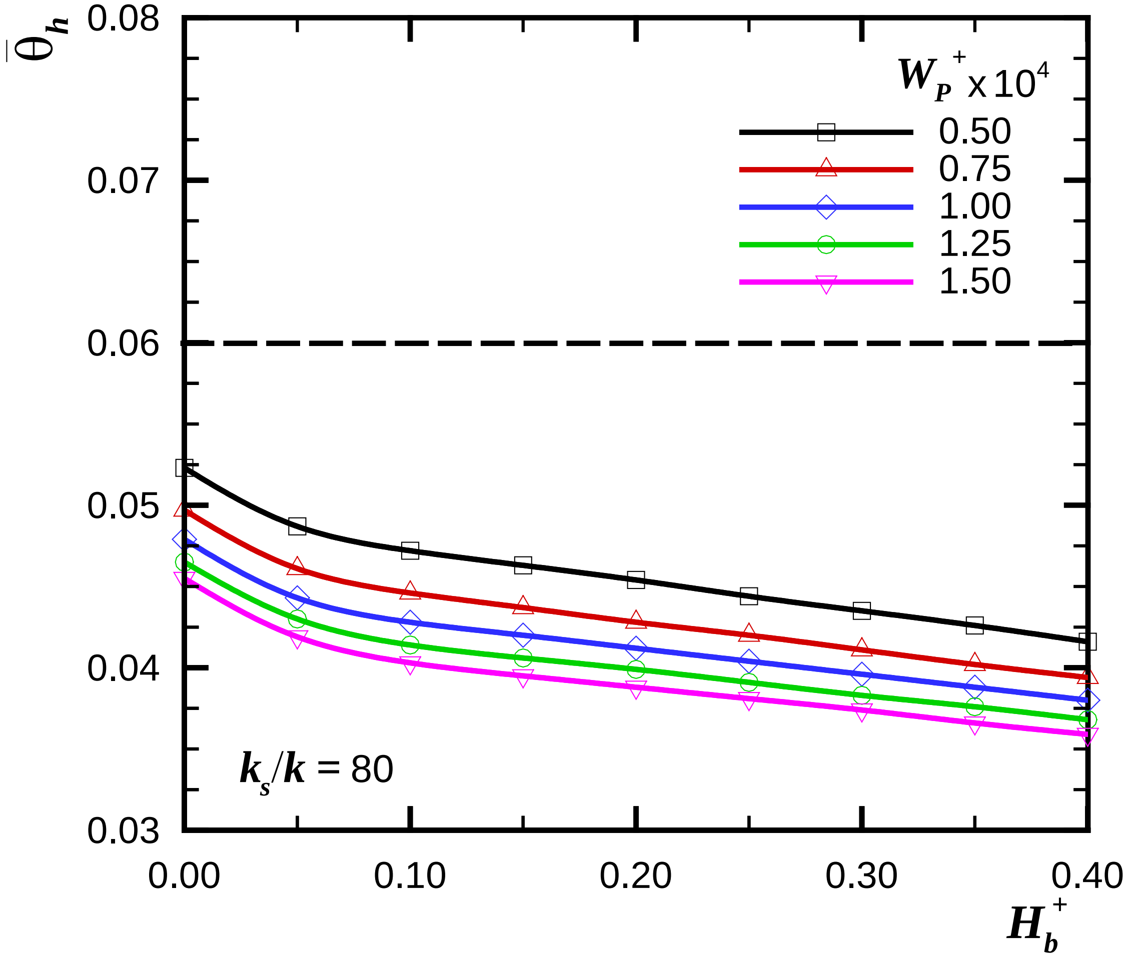

Figure 14 : Heater average temperature – fixed pumping power and $(k_s/k) = 80$

IV. Conclusions

The heater dimensionless average surface temperature (or its global thermal resistance) always decreased when either the airflow rate or the substrate plate thermal conductivity increased.

For a fixed flow rate, the heater temperature decreased as the heater height and the substrate thermal conductivity increased. Besides that, the flow pressure drop and the required pumping power increased with the heater height and the flow rate in the channel. In order to avoid that the flow recirculation zone downstream of the heater extended beyond the channel length at the largest *Re*, the relative heater height was limited to 0.40.

Under the constraints of a channel flow driven either by a fixed pressure drop or by a fixed pumping power, the flow rate decreased as the heater height increased, due to channel obstruction. In these cases there is a critical heater height which minimizes its thermal resistance to the airflow. The heater thermal resistance and temperature will increase with a heater height taller than this critical value. This behavior has no counterpart under the fixed flow rate constraint.

Under any flow constraint, considering an adiabatic substrate, there is a minimum heater height needed to keep it below a maximum allowable temperature. This required height decreases as the channel flow rate and the substrate thermal conductivity increase. In the present investigation, up to 50 per cent of the heater dissipation rate was spread by conduction through the substrate plate before returning to the airflow. This corroborates the potential of the conductive substrate to reduce the heater temperature or its global thermal resistance to the channel flow.

V. Acknowledgement

The support of CNPq (Brazilian National Research Council) to the first author is gratefully acknowledged.

- NOMENCLATURE

c = specific heat, J/kgK
c^+ = dimensionless unity thermal capacity
g = gravitational acceleration, m/s^2
Gr = Grashoff number
H = channel height, m
H_b = heater height, m

H_b^* = dimensionless heater height
H_b^+ = dimensionless heater height
L = total channel length, m
L_b = block heater length, m
L_d = channel downstream length, m
L_r = recirculation zone length downstream of the heater, m
L_u = channel upstream length, m
L_b^* = dimensionless heater length
L_r^+ = dimensionless recirculation zone length downstream of the heater
k = air thermal conductivity, W/mK
k_b = heater thermal conductivity, W/mK
k_s = substrate thermal conductivity, W/mK
k^+ = dimensionless thermal conductivity relative to air
P_W' = pumping power per unit depth, W/m
Pr = air Prandtl number
q' = heat generation per unit depth, W/m
q_{cd}' = heat conducted through the substrate plate per unit depth, W/m
q'' = heat flux, W/m^2
Re = Reynolds number, Eq. (1)
R_t' = global thermal resistance per unit depth, Eq. (8)
S^* = dimensionless volumetric source term, Eq. (6)
t = substrate thickness, m
T = temperature, K
u = x-velocity component, m/s
U = dimensionless x–velocity component
v = y-velocity component, m/s
V = dimensionless y–velocity component
x, y = Cartesian coordinates, Fig. 1, m
X, Y = dimensionless Cartesian coordinates
W_p^+ = dimensionless pumping power

a) Greek Symbols

β = coefficient of thermal expansion of the fluid, 1/K
Δp = pressure drop, Pa
Δp^* = dimensionless pressure drop
Δp^+ = dimensionless pressure drop
ρ = density, kg/m^3
θ = dimensionless temperature, Eq. (15)
υ = kinematic viscosity, m^2/s

b) Subscripts

h = heater
max = maximum value
0 = channel inlet

c) Superscripts

– = average

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Optimum Design of Compound Pressure Vessel

By Md. Tanjin Amin, Aminur Rahman & Dr. Abu Rayhan Md. Ali
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Abstract- Effect of compounding investigated theoretically by finite element modeling. The variables are interference radius & shrinkage tolerance. Equivalent von Mises stress is used as yield criterion to evaluate the optimum interference radius. For two different working pressure the effect of the ratio of outer & inner radius (b/a=k) value on the optimum interference radius is also noticed. The optimum interference radius solely depends on shrinkage tolerance. Furthermore, percentage reduction of von Mises tolerance is compared for different working pressures & different k values as well as for different materials.

Keywords: autofrettage, residual stress, von mises stress, working pressure, pressure vessel, elasto-plastic junction.

GJRE-A Classification : FOR Code: 091399p

OPTIMUMDESIGNOFCOMPOUNDPRESSUREVESSEL

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Optimum Design of Compound Pressure Vessel

Md. Tanjin Amin [α], Aminur Rahman [σ] & Dr. Abu Rayhan Md. Ali [ρ]

Abstract- Effect of compounding investigated theoretically by finite element modeling. The variables are interference radius & shrinkage tolerance. Equivalent von Mises stress is used as yield criterion to evaluate the optimum interference radius. For two different working pressure the effect of the ratio of outer & inner radius (b/a=k) value on the optimum interference radius is also noticed. The optimum interference radius solely depends on shrinkage tolerance. Furthermore, percentage reduction of von Mises tolerance is compared for different working pressures & different k values as well as for different materials.

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I. Introduction

Compound cylinders are widely used in the field of high pressure technology such as hydraulic presses, forging presses, power plants, gas storages, chemical and nuclear plants, military applications etc. To enhance load bearing capacity and life of multilayer pressure vessels, different processes such as shrink fit and autofrettage are usually employed. Shrink fit increases load capacity. Many researchers have focused on methods to extend lifetimes of vessels. Majzoobi et al. have proposed the optimization of bi-metal compound cylinders and minimized the weight of compound cylinder for a specific pressure [1]. The variables were shrinkage radius and shrinkage tolerance. Patil S. A. has introduced optimum design of two layer compound cylinder and optimized intermediate, outer diameter and shrinkage tolerance to get minimum volume of two layer compound cylinders [2]-[3]. Hamid Jahed et al. have investigated the optimum design of a three-layered vessel for maximum fatigue life expectancy under the combined effects of autofrettage and shrink fit [4]. Miraje Ayub A. & Patil Sunil A. have found minimum volume of three-layer open type compound cylinder considering plane stress hypothesis [5]. Yang Qiu-Ming et al. have presented a simple and visual tool to calculate the residual stress and describe the distribution of residual stress for both the elastic-perfectly plastic model and the strain-hardening mode [6].

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II. Analytical Approach

As stated earlier, an elasto-plastic behavior has been designated in this work.

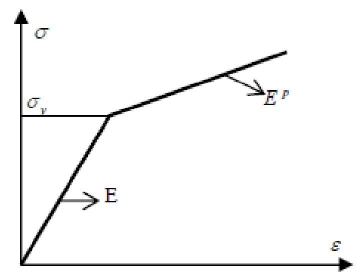

Figure 1 : Bi-linear Stress Strain Curve

The model, shown in fig. 1 is described as follows:

$$\sigma = \sigma_y + E^P \varepsilon \qquad (1)$$

In which, σ is the effective stress, σ_y is the initial yield stress, E^p is the slope of the strain hardening segment of stress strain curve, and ε is the effective strain.

a) *Tangential & Radial Stress Pattern*

To observe the stress pattern in a compound cylinder, a sample cylinder with internal diameter a = 0.1m, interference radius c = 0.15m, and external radius b = 0.20m has been considered. Material Properties of this cylinder summarized in table I

Table 1 : Material Properties

Material	σ_y(MPa)	E(GPa)	υ
Steel	800	207	0.29

An outer cylinder with the internal diameter slightly smaller than the outer diameter of the main cylinder is heated and fitted onto the main cylinder. When the assembly cools down to room temperature a compound cylinder isobtained. In this process the main cylinder is subjected to an external pressure leading to a compressive radial stress at the interface. The outer cylinder or the jacket is subjected to an internal pressure leading to a tensile circumferential stress at the inner wall. Under this condition as the internal pressure increases the compression in the inner cylinder is first released and then only the cylinder begins to act in tension.

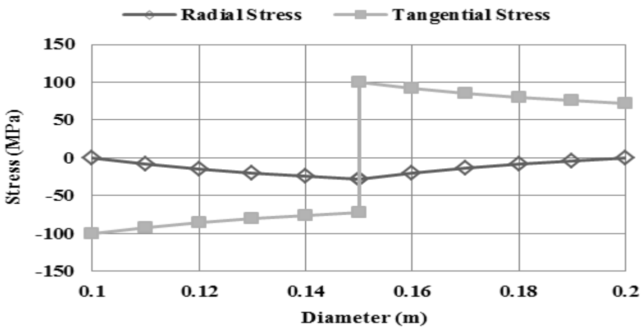

Figure 2 : Radial & Tangential Stress Distribution through the Walls of a Compound Cylinder

Though outer cylinder is fitted on the top of the inner cylinder, a compressive stress is developed in the near bore region. Here in the fig. 2, compressive stress is developed in the inner diameter while tensile stress occurs at the outer portion. Here the initial stress is compressive so if internal pressure is applied, then a tensile stress will be developed & this tensile stress even quite high, but the resultant stress not that high because of this compressive stress.

b) Comparison of Stress between Single cylinder & Compound Cylinder

By using Lame's equation for thick-walled cylinder, the stress pattern is obtained for both single cylinder & compound cylinder. If these two cylinders undergoes same internal pressure then the overall stress pattern will change, which is shown in Fig. 3, here the internal pressure is 250 MPa.

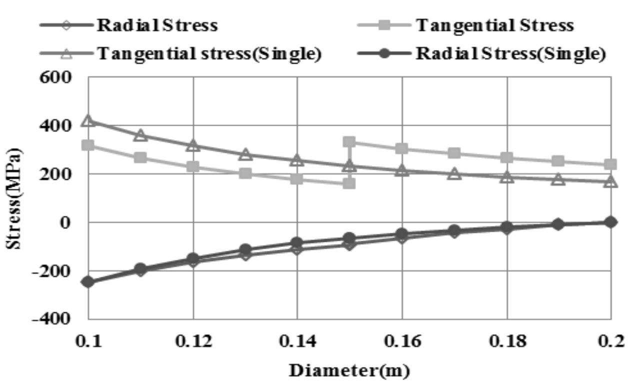

Figure 3 : Comparison of Stresses between Single & Compound Cylinder

Because of the compressive tangential stress at inner bore, the resultant tangential stress becomes lower in the compound cylinder than the original tangential stress developed at the single cylinder. Radial stress doesn't vary significantly after compounding. Radial stress doesn't vary significantly after compounding. Maximum stress occurs at the junction point of inner & outer cylinder rather than inner bore.

c) Comparison of Overall von Mises Stresses

According to the third strength theory, the equivalent stress is as follows [12]-[13]:

$$\sigma_{eq}^{III} = \sigma_t - \sigma_r \qquad (2)$$

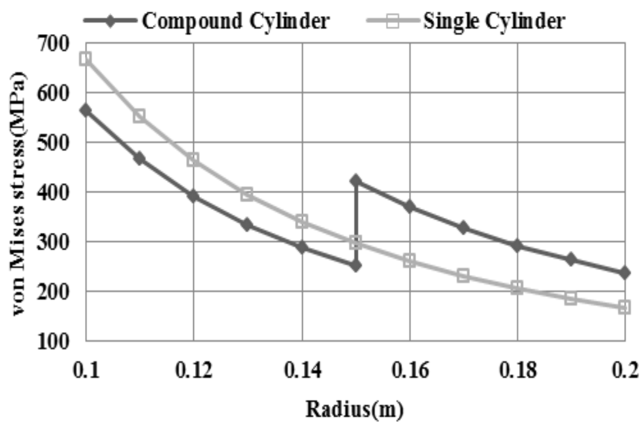

Figure 4 : Comparison of von Mises stresses between Single & Compound cylinder according to the third strength theory

The equivalent stress based on the fourth strength theory is as follows [12[-[13]:

$$\sigma_{eq}^{IV} = \sqrt{\frac{1}{2}\left[(\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_z)^2 + (\sigma_z - \sigma_t)^2\right]} \qquad (3)$$

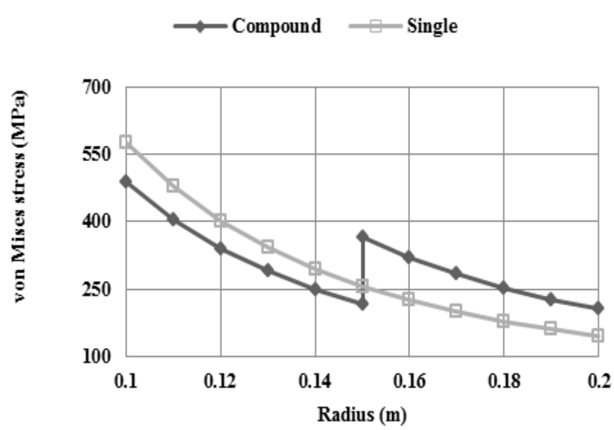

Figure 5 : Comparison of von Mises stresses between Single & Compound cylinder according to the third strength theory

Substituting $\sigma_z = (\sigma_t + \sigma_r)/2$ (Lame formula) Eq.(2), we obtain:

$$\sigma_{eq}^{IV} = \frac{\sqrt{3}}{2}(\sigma_t - \sigma_r) = \frac{\sqrt{3}}{2}\sigma_{eq}^{III} \qquad (4)$$

Eq. (3) s the relation between the third & the fourth strength theory for a cylinder and also the relation between the Tresca's & Mises yield form.

As the fig. 4 & 5 suggest, maximum von Mises stress starts to decreases from inner bore to junction of two cylinders. Stress suddenly increases because of the contact pressure between two mating surface. It again decreases from junction point to outer portion.

i. *Sample calculation*

- In this case study, a=0.1m, b=0.2m, c=.15m, working pressure, Pworking = 250MPa.
- From third strength theory, MVS = 666 MPa
- From fourth strength theory, MVS =577 MPa
- From these two theories, it is observed that MVS for both is very similar. Indeed there is no significant variation between these two methods.
- Fourth strength theory is considered for all comparison.

III. Numerical Result

The compounding process may be simulated by Finite Element Method, making use of elastic-plastic analysis. It is possible to model the compound cylinder by applying pressure to the inner surface of the model, and then analyzing it for different interference radius & different shrinkage tolerance.

Using a 3D axisymmetric element available in *ANSYS V11* SP1*,* a finite element mesh of a cylinder with an inside radius 100 mm and outside radius of 200 mm was generated. An internal pressure of 250 MPa was applied. The stress distributions were evaluated in the compound cylinder. The von Mises equivalent stress was used in the subsequent analysis.

Structural Steel of flexible stiffness behavior has been used. Compound cylinder with the dimension; a = 0.1 m, b = 0.2 m, an elastic plastic material's model with σ = 800 MPa; Modulus of elasticity E = 207 GPa; ν = 0.29; were used for numerical modeling.

Here, the effects of following factors are considered in the compounding process. The considered factors are:

- Interference radius; 2. Value of k (b/a); 3. Different material at inner cylinder.

a) Change of Interference Radius

The cylinders were subjected to different internal pressures of 100, 200 and 300 MPa. From the numerical simulation with ANSYS software, the curve of the von Mises stress distribution was obtained for each working pressure. From the curve, the values of maximum von Mises stresses (MVS) were extracted. This stresses were then plotted against interference radius for each working pressure. The results are shown in fig. 6.

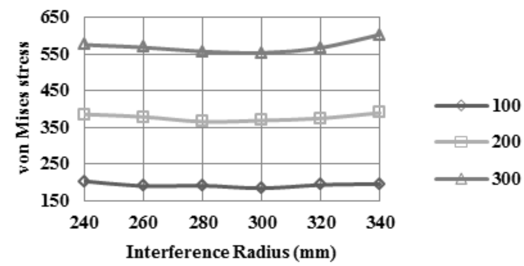

Figure 6 : Variation of MVS verses interference radius at different working pressure

It is observed that with the increase of interference radius, the MVS decreases slightly. Because at small interference radius, lower contact pressure is developed at the junction of the two cylinders. When the radius increases then the contact pressure increases and there is much compressive stress at the inner bore region resulting lower MVS. With the increase of interference radius much stress is developed at the outer cylinder; resulting a higher overall stress distribution.

The value of MVS is calculated for different interference radius for different working pressures.

Table 2 : Von Mises Stresses at Different Interference Radius for Different Working Pressure

Interference Radius (mm)	Pressure 100 (MPa)	Pressure 200 (MPa)	Pressure 300 (MPa)
240	203	386	576
260	190	379	569
280	191	366	558
300	184	369	554
320	193	375	568
340	195	390	604

From the table II, it is observed that the minimum values of MVS are at 280 mm & 300 mm. This means in those radius tangential stresses at inner wall of inner cylinder and inner wall of outer cylinder almost same.

For a constant value of interference radius (280 mm) the percent reduction of MVS is calculated for different working pressure.

Table 3 : Effect of Working Pressure at Maximum Von Mises Stress

Working Pressure (MPa)	MVS of single cylinder (MPa)	MVS of compound cylinder (MPa)	% reduction of MVS
100	233	191	18.03
200	467	366	21.63
300	701	558	20.40

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From the table III, it is observed that the percent reduction of MVS is higher at moderate & higher working pressures.

b) Change of Shrinkage Tolerance

In the preceding case minimum MVS was found in between 280 mm & 300 mm of interference radius. Now the cylinder is subjected to a working pressure 200 MPa and interference radius is considered as 280 mm. From the curve, the values of maximum von Mises stress (MVS) are extracted. This stresses are then plotted against the shrinkage tolerance. The results are shown in fig. 8.

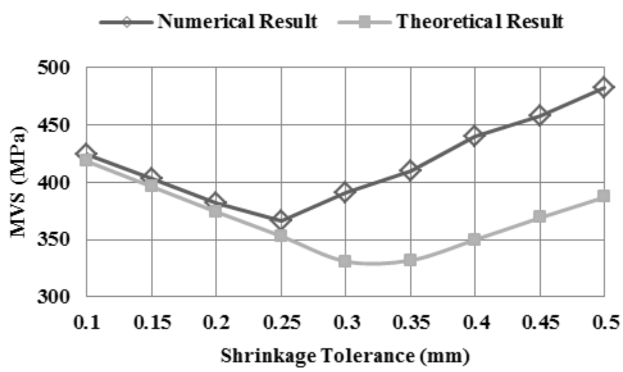

Figure 8 : Variation of MVS versus different shrinkage tolerance

It is observed that the developed MVS starts to decrease with the increase of the shrinkage radius. With the increase of the shrinkage radius, the compressive stress in the inner bore region increases & so that MVS decreases. But after a certain point with the increase of the shrinkage radius, MVS increases because then the stress of the inner bore of the outer cylinder increases. And also there is a close relation between the numerical result & theoretical result shown in the fig. 8.

c) Values of k

- Constant inner diameter

For constant inner radius (a = 0.1m) of the inner cylinder & constant interference radius, c = 280 mm cylinder with different k values (k=2, 2.5, 3) are subjected to same working pressure.

Here the working pressure remains constant at $P_{working}$ = 200 MPa

From numerical simulation, the value & the position of MVS are extracted. This MVS is then plotted against the diametral interference for each k value. The results are shown in fig. 9

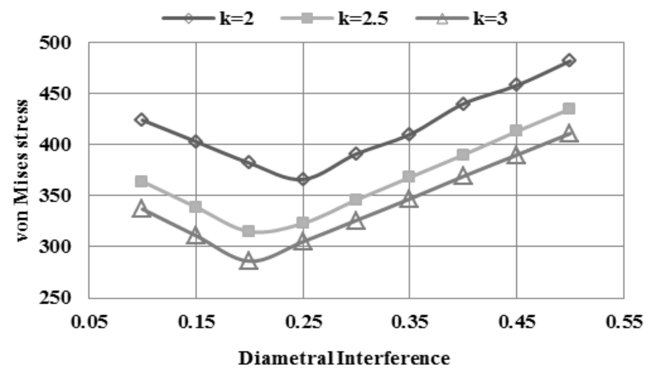

Figure 9 : Effect of k (b/a) on the diametral interference (constant inner radius = 0.1m)

As in fig. 9, suggests for different values of k, the minimum MVS obtains a higher value of thicker cylinder at lower diametral interference.

For a constant working pressure (Pworking = 200 MPa), percent reduction of MVS is calculated for different k values.

Table 4 : Effect Of K = (B/A) On Mvs At Constant Inner Radius

k	MVS of single cylinder (MPa)	MVS of compound cylinder (MPa)	% reduction of MVS
2.0	467	366	21.63
2.5	414	315	23.91
3.0	392	286	27.04

From table IV, it is observed that, percent reduction of MVS is higher for higher value of k. So, the process is more beneficial with the increase of the thickness of the cylinder.

- Constant outer diameter

In the preceding case the inner radius of the inner cylinder was kept constant. Now by assuming the outer radius (b= 0.2m) constant, cylinder with three k values of 2.0, 2.5, 3.0m are considered. From the numerical simulation, the curve of MVS distribution is obtained for each value. The developed MVS are then plotted against diametreal interference at fig. 10.

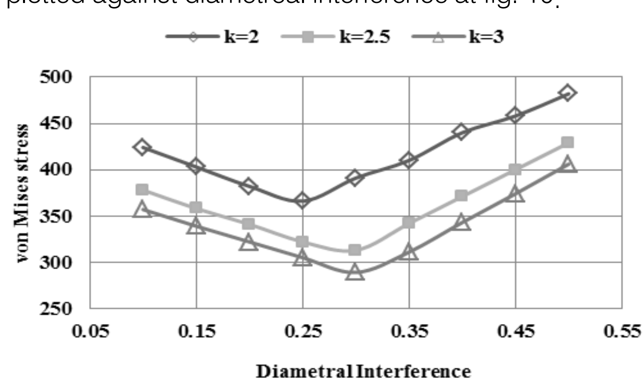

Figure 10 : Effect of k (b/a) on the diametral interference (constant outer radius = 0.2m)

As in fig. 10, suggest for different values of k, the minimum MVS obtains a higher value of thicker cylinder at higher diametral interference.

For a constant working pressure (Pworking = 200 MPa), percent reduction of MVS is calculated for different k values.

Table 5 : Effect Of K = (B/A) On Mvs at Constant Outer Radius

k	MVS of single cylinder (MPa)	MVS of compound cylinder (MPa)	% reduction of MVS
2.0	467	366	21.63
2.5	415	313	24.57
3.0	392	289	26.28

From the table V, it is noticed that for same k value, developed MVS is almost same though the value of inner & outer radius have been changed. So the optimum diametral interference depends on k value only. If the inner & outer radius are changed keeping the k value constant, then there will be no such change in diametral interference.

From above two graphs it can be said that, constant inner radius of inner cylinder is more effective than other one. Because in inner radius constant process the minimum von Mises stress found in lower diametral interference.

d) Different Material as inner cylinder

Now inner cylinder of the compound cylinder is replaced by cast iron cylinder and copper cylinder respectively. Here the working pressure remains constant at $P_{working}$ = 200 MPa From the numerical simulations, the curve of von Mises stress distribution is obtained for different material model. From the graph, the value & the position of the maximum von Mises stress are extracted and plotted against diametral interference.

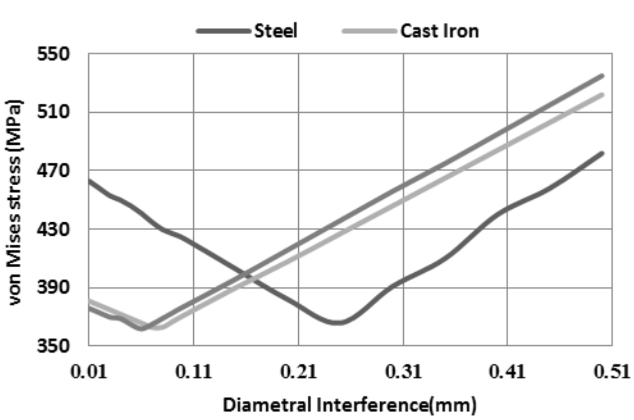

Figure 11 : Effect of different material on diametral interference

From the fig. 11, it is observed that cast iron & copper alloy shows minimum von mises stress at small diametral interference. This means if material of low tensile stress is compounded by a high tensile stress material, then at lower diamteral interference they show the desired effect.

Here cast iron & copper alloy are separately shown in fig. 12.

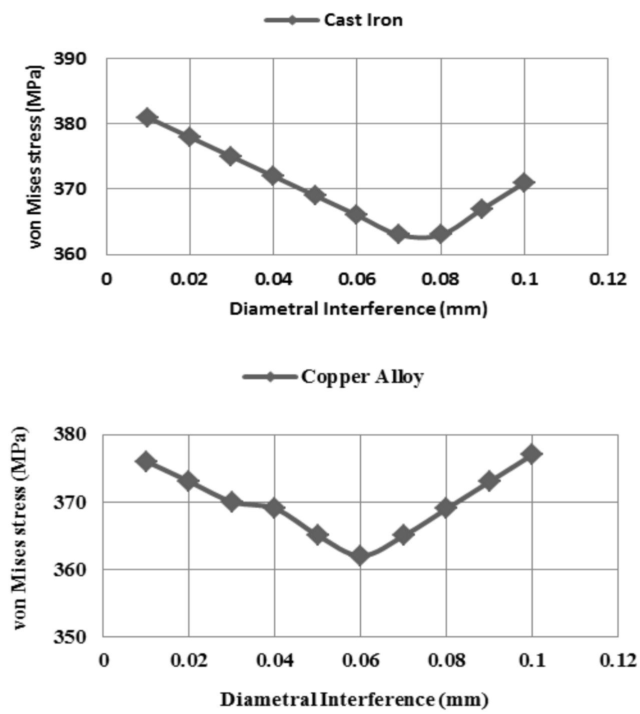

Figure 12 : Effect of different material on diametral interference (Cast iron & Copper alloy)

From fig. 12, it is noticed that, these two metals jacketed by steel work better at small diametral interference.

IV. Conclusion

The following decisions can be taken from the investigations mentioned in this paper:

1. In compound cylinder, maximum von Mises stress does not occur at smaller interference radius instead of that, it occurs at midway section.
2. Maximum stress depends on the interference radius as well as diametral interference.
3. The optimum diametral interference depends on k value only rather than inner & outer radius.
4. The thicker the cylinder the more will be the reduction in MVS.
5. Two element cylinder of different material reduces diametral interference more than two element cylinder of same material.

6. The size of a compound cylinder could be reduced by significant amount with respect to its equivalent single cylinder for the same working pressure.
7. The difference between a compound cylinder and its equivalent single cylinder becomes more significant at higher working pressures.

Appendix

Table : Nomenclature

Symbol	Meaning	unit
a	Inner radi	(m)
b	Outer radius	(m)
c	Interference ı	(m)
σ_y	Yield stress	(MPa)
σ_θ	Tangential s	(MPa)
σ_r	Radial stress	(MPa)
σ_z	Longitudinal	(MPa)

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Bahera (T. Bellirica) Biodiesel Production in Bangladesh, Characterization of Bahera Biodiesel and its Performance on a Diesel Engine

By Md. Shamim Akhter, Abul Hasanat & Md. Eyasin Arafat
Rajshahi University of Engineering & Technology, Bangladesh

Abstract- Petroleum oil which is limited due to its reserve capacity is the prime source of fuel in the world as well as Bangladesh. The concerning depletion rate of Petroleum oil leads to go for alternative fuels. T. bellirica (bahera) biodiesel is a sustainable alternative fuel and is eco-friendly though the extraction is costly. Biomass is collected from Bangladeshi forest and oil is extracted from kernel containing of about 40% oil. The oil is extracted by the solvent extraction process using soxhlet apparatus. It has been found that the oil contains free fatty acid of about 0.87% which is turned into biodiesel by the transesterificationl by reacting methanol with lipid oil in the presence of base catalyst sodium hydroxide. The physiochemical properties of Bahera Methyl Ester (BME) biodiesel are investigated with the various experimental processes. The different physiochemical properties include density, kinematic viscosity, cetane number, calorific value, flash and fire point, cloud point, pour point, acid value, elemental analysis and boiling range. The results show that all properties are compatible with standard values of other biodiesels.

Keywords: T. Bellirica, BME, biodiesel, physiochemical properties, transesterification, performance parameters.

GJRE-A Classification : FOR Code: 850506, 850499p

BAHERATBELLIRICABIODIESELPRODUCTIONINBANGLADESHCHARACTERIZATIONOFBAHERABIODIESELANDITSPERFORMANCEONADIESELENGINE

Strictly as per the compliance and regulations of:

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Keywords: T. Bellirica, BME, biodiesel, physiochemical properties, transesterification, performance parameters.

I. Introduction

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground-based carbon resources. The search for alternative fuels, which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced in the present context. The technology of biodiesel production from vegetable oil feed stockis clearly defined, although the process economics may be improved by selection of lower cost feedstock, which does not have the pitfalls like limited supply potential and high oil costs (Azam et al., 2005). Rashid et al. (2008) has reported the use of Moringa oleifera oil as a possible source of biodiesel. The potential of Sesamum indicum seed oil was also studied for biodiesel manufacturing (Saydut et al., 2008). In continuation of our work on exploring new bioresources (Sarin et al., 2009), the study on potential of Terminalia bellirica (T. bellirica) as biodiesel resource is reported here.Biomass T. bellerica is a potential source of biodiesel which is transesterified to obtain biodiesel getting acceptance under the concern mentioned above.

T. Bellerica is commonly called as bahera under the family of Combretaceae. Deciduous forests are the main land of it. It is found in indian subcontinent in large proportion particularly in Bangladesh.

It is a large tropical deciduous tree, whose height is upto 30-40 m and 1.8-3.0 m in girth. Bark is colour of blue and ash grey containing numerous longitudinal cracks. It can be cultivated in almost all over Bangladesh though preferable in tropical and subtropical areas. It takes 6 to 8 years to mature and produce 500 kg fruits annually. The fruits are globular containing a hard thick shelled. Fruits are collected during winter which ripens at the end of rainy season. Chemically T. bellerica contains phenolics, sugars, gallics acid, belleric acid and β-sitosterol. It has medicinal values for the treatment of liver and digestion disorders (Anand et al., 1997). The dry fruits of T. bellerica also possess potential broad spectrum antimicrobial activity (Elizabeth, 2005).It is also used as medicine to treat several illnesses, such as fever, cough, diarrhea, skin diseases and oral thrush. There is no statistics of the utilization of T. bellerica kernel as a resource for biodiesel inducement.

Many researchers have shown that (Pullagura et al., 2012) using raw vegetable oils for diesel engines can cause numerous problems. Vegetable oils have increased viscosity, low volality, cold flow properties and high cetane number causing injector cocking, piston ring sticking, and fuel pumping problem with deposits on engine. For this reason the vegetable oil cannot be used direct in engine instead of conventional diesel. However the above limitation can be greatly minimized by converting the vegetable oil into ester through esterification which is named as bio-diesel.

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II. Materials and Methods for Biodiesel Preparation

a) Raw Materials

Mature and raw fruits of T. bellirica were collected from local trees. The seeds were dried in the sun for about five weeks. The sun-dried all seeds. Then they are stored in a room at normal temperature. After drying, the weight of the seeds was about 11.2 kg. The kernels were separated from the fruits by scraping the fruit pulp (pericarp) manually and stored in an airtight container for experimental purpose. After drying, seed kernels were ground into powder by a ball mill. The weight of the dried powder was 1.44 kg that is the 12.8% of dried T. bellirica seeds. Then the oil was extracted from the dried and powdered meal with hexane using a soxhlet or solvent apparatus.

b) Oil Extraction

Thimble of soxhlet apparatus was filled with crushed kernel powder of T. bellirica seeds. Then, the upper part of the thimble was covered with thick paper and attached to the mouth of a round bottomed flask containing n-hexene as an extractive solvent. Some boiling chips were added into the flask to avoid bumping during heating. For completing the extraction through desired number of cycles, the refluxing was continued for 6 hrs. Then the solvent was removed by a rotary evaporator from mixing of oil and solvent. The separated oil was stored in a bottle. The amount of extracted oil is 29.86% by mass of the crushed kernel.

c) Refining Process

Crude extracted T. belerica oil contains impurities like free fatty acid (1.68%), moisture content (0.15%) and contaminants such as P (220 ppm), Ca (68 ppm), Mg (30 ppm), Mn (2 ppm) and Zn (16 ppm). The oil was refined by total degumming process (Zufarov et al., 2008), involving treatment with phosphoric acid and sodium hydroxide. The processed oil was dissolved in n-hexane and washed with distilled water. The pure oil was obtained by evaporation of hexane. Collected oil was found to have P (<10 ppm), Ca (5 ppm), Mg (2 ppm), Mn (<1 ppm) and Zn (2 ppm), free fatty acids (0.05%) and moisture (400 ppm).

d) T. Bellirica Methyl Esterization

Reactions were carried out in a 500 ml beaker, equipped with a thermometer and a mechanical stirrer. Methanol was poured to the beaker, followed by slow addition of sodium hydroxide catalyst (0.35% wt. of oil) with stirring. The stirring was continued till the complete dissolution of the catalyst (15 min). Desired quantity of T. bellirica oil was added and the reaction mixture was heated at 650C temperature. Progress of the reaction was monitored by TLC (Thin Layer Chromatography) at regular intervals. After completion of the reaction, the material was transferred to separator and both the phases were separated. Upper phase was biodiesel and lower phase was glycerine. Methanol from both the phases was distilled off under reduced pressure. Biodiesel layer was washed with hot water to remove the traces of glycerine, unreacted catalyst and soap formed during the transesterification and subsequently dried under reduced pressure. The product obtained (>98%) was sufficiently pure for testing. Statistical analysis of biodiesel synthesized from T. bellirica was done on the basis of experimental results in terms of ester conversion and yield calculated. Average yield and ester conversion were 98% and 98.5%, respectively, with standard deviation of 0.44% and 0.31%.

III. Result and Discussion

a) Quantity of Biodiesel production in Bangladesh

In Bangladesh biodiesel from Bahera oil can be produced and the quantity of biodiesel can be calculated as follows:

- Unused land in Bangladesh: 0.32 million hectare
- Expected seed per hectare per annum: 9 MT [Sureshkumar et al., 2008]
- Expected Bahera oil per hectare per annum: 1.3 MT (Considering 38% conversion from seed kernel to oil)
- Expected biodiesel production per hectare per annum:1.27 MT (98% conversion)
- So, in 0.32 million hectare land, the amount of biodiesel production will be 0.41 million MT per year. As Bangladesh imports 2.4 million MT diesel fuel each year, the country can reduce importing automotive diesel fuel by 17%.

b) Oil Characterization

The physico-chemical properties of T. bellirica oil vis-a-vis jatropha, sunflower, soybean and rapeseed oils is given in Table 1 which is the earlier reported data (Agarwal et al., 2007; Ramadhas et al., 2005) for comparison with T. bellirica. T. bellirica seed oil is a mixture of triglycerides of a variety of fatty acids. On the basis of GC analysis, six types of fatty acids were determined and quantified. These fatty acids showed vary in carbon chain length and in the extent of unsaturation. Fatty acid profile of T. bellirica seed oil was palmitic acid, 11.6%; stearic acid, 3.9%; ecosanoic acid, 0.8%, oleic acid, 61.5% and linoleic acid, 18.5% which was determined by GC agrees with the earlier literature on T. bellirica (Bera et al., 2007). T. bellirica seed oil is contain about 20% and 80% of the total saturated and unsaturated fatty acid composition respectively. It is very resemble to rapeseed oil in oleic and linoleic glyceride content and resemble to soybean oil in saturated acid glycerides. Physico-chemical properties of T. bellirica seed oil and other four oils are also given in Table 1. The table shows that the acid value of the crude T. bellirica oil and jatropha were higher (3.36 and 3.80 mg KOH/g) than sunflower (0.15 mg KOH/g), soybean (0.20 mg KOH/g) and rapeseed oil (1.14 mg KOH/g).

The density of T. bellirica seed oil is moderately higher (929 kg/m3) than other oils. The cloud point and pour point of T. bellirica oil and jatropha oil are (8°C and 3°C/ 6°C), which is higher than sunflower, soybean and rapeseed oil. Oils which are more unsaturated are oxidized more quickly than less unsaturated oils as shown in the Table 1.T. bellirica seed oil oxidation stability is found to be 8.68 h.

Table 1 : Physical properties of T. Belerica with different vegetable oils

Physical property	Test method	T. belerica oil	Jatropha oil	Sunflower oil	Soybean oil	Rapeseed oil
Fatty acid profile (%)	ASTM D-1983					
Saturated fatty acids						
Palmitic acid $C_{16:0}$	-	11.6	14.2	6.8	11.75	3.49
Stearic acid $C_{18:0}$	-	3.9	6.8	3.25	3.15	0.85
Eicosanoic acid $C_{20:0}$	-	0.8	-	-	-	-
Monounsaturated fatty acids						
Palmitoleic acid $C_{16:1}$	-	-	1.1	-	-	-
Oleic acid $C_{18:1}$	-	61.5	43.1	16.93	23.26	64.4
Polyunsaturated fatty acids						
Linoleic acid $C_{18:2}$	-	18.5	34.3	73.73	55.53	22.3
Linolenic acid $C_{18:3}$	-	-	0.5	-	6.31	8.23
Acid value (mg KOH/g)	ASTM D-974	3.36	3.80	0.15	0.20	1.14
Viscosity at 40°C (mm2/s)	ASTM D-445	39.8	37.0	33.9	32.6	37.0
Density (kg/m3) at15°C	ISO 3675	929	910	916	913	911
Iodine value	-	85	99	142.2	132.6	115.5
Cloud point (°C)	ASTM D-2500	8°C	8°C	7.2°C	-3.9°C	-3.9°C
Pour point (°C)	ASTM D-97	6°C	3°C	-15°C	-12.2°C	-31.7°C
Oxidation stability (h)	EN 14112	8.68	2.56	1.0	2.5	10.5″
Water content, (%)	ASTM D-1123	0.15	0.17	NR	NR	NR

NR: Not Reported

Reported by Agarwal (2007) and Krygier and Platek (1999)

The presence of Gallic acid (3, 4, 5-trihydroxy benzoic acid) which acts as antioxidant (Bera et al., 2007). Unsaturation of oil is described by the iodine value and the determination of iodine value of vegetable oils and methyl ester of some oils from fatty acid composition as per AOCS Cd 1c-85 method has reported earlier (Petursson et al, 2002).

In this method, iodine value measured is about 85 (Table 1), which embraces dominantly octadecenoic triglyceride (oleic acid) vis-a-vis jatropha, sunflower, soybean and rapeseed oil. The iodine value is correlated with viscosity, which narrates that the viscosity decreases linearly with the iodine value increases (Abramovic and Kloufutar et al., 1998). The viscosities of vegetable oil were positively correlated with the amounts of monounsaturated fatty acid (i.e., viscosity increased with increase in fatty acid) and negatively correlated with the amount of polyunsaturated fatty acid, respectively (i.e., viscosity decreased with increase in fatty acid) which was reported by (Fasina et al., 2006). The values of viscosity of the respective vegetable oil methyl esters are reduce after transesterification process.

c) T Bellerica Methyl Ester Characterization

The synthesized methyl ester (Biodiesel) properties were determined and compared with Jatropha and Sunflower methyl ester as shown are in Table 2. The fuel properties of methyl esters synthesized from Jtropha and Sunflower were determined (Sarin et al., 2007) against the relevant specification of biodiesel ASTM D-6751 standard.

In general, the properties of biodiesel meet the standard of all the important properties estimated. The acid value of T. bellerica methyl ester is 4.5544 mg KOH/g, higher than the estimated acid value 0.014 mg KOH/g. Also it is higher than the acid value of jatropha (0.48 mg KOH/g), sunflower (0.20 mg KOH/g) and soybean (0.15 mg KOH/g). The flash point of synthesized biodiesel is 162^{0}C.The variation of flash point of Jatropha and sunflower methyl ester is in a specified limit. Where, the flash point of jatropha is higher in 1^{0}C than that of T.bellirica.

Table 2 : Comparison of T. bellirica methyl ester properties with Jatropha and Sunflower methyl ester

Property(units)	T.billerica		Jatropha	Sunflower
Acid number(mg KOH/g)	4.5544		0.48	0.20
Free fatty acid (%)	0.87		ND	ND
Flash point(^{0}C)	162		163	180
Viscosity at 40^{0}C (mm^2/s)	5.936		4.40	4.10
Cloud point(^{0}C)	5		4	4
Pour point(^{0}C)	1		0	ND
Cetane number	53.4		57.1	55.6
Oxidation stability(h)	2.09		3.23	1.73
Free glycerin(% mass)	0.003		0.01	0.02
Total glycerin(% mass)	0.011		0.02	0.02
Density at 15 C(g/cc)	0.9077		ND	ND
Boiling range(^{0}C)	IBP*	90	ND	ND
	10	280		
	20	284		
	30	286		
	40	286		
	50	290		
	60	296		
	70	304		
	80	338		
	84	338		

IBP*: Initial Boiling Point

ND: Not Determined

The value of kinematic viscosity of T. bellirica methyl ester at 40^{0}C is 5.936 mm^2/s, jatropha (4.40 mm^2/s) and sunflower (4.10 mm^2/s) are less viscous under the same temperature condition, which is reasonable for a biodiesel. Cloud point of it higher also in 1^{0}C than that of those are compared in the table. The pour point of T. bellirica is 10C; the standard value of biodiesel is 0^{0}C. the cetane number provides a measure of the ignition characteristics of diesel fuel. The table exhibits that the cetane number is slightly higher than standard of the respective value. The oxidation stability of fuel is 2.09 h, comparable with jatropha 3.23 h slightly more stable and 1.73 h less stable than T .bellirica. Fuel meets the free (.003%) and total (0.11%) glycerol content with the standard 0.02% for free glycerol and 0.25% for total glycerol which is lower than jatropha and sunflower. Density of fuel at 150C is 0.9077 g/cc, in line with the standard 0.88 g/cc. The key properties of biodiesel is boiling range, the last value of the range indicates the initial boiling point which for the fuel is 84-338^{0}C.

Table 3 : Comparison of T. bellirica fuel properties with standard value of diesel and biodiesel

Property	Diesel	Standard biodiesel	T. bellirica
Composition	Fatty acid methyl ester(c_{10}-c_{21})	Fatty acid methyl ester(c_{12}-c_{22})	Fatty acid methyl ester(c_{12}-c_{22})
Specific gravity(g/ml)	0.85	0.88	0.9077
Viscosity at 40 ^{o}C (mm^2/sec)	1.3-4.1	1.9-6.0	5.936
Flash point(^{0}c)	60-80	100-170	162
Cloud point (^{0}c)	-15 to 5	-3 to 12	5
Pour point (^{0}c)	-30 to -15	-15 to 16	1
Carbon (wt.%)	87	77	ND
Water(vol.%)	0.05	0.05	0.07
Cetane number	40-55	48-60	53.4
Sulphur(wt.%)	0.05	0.05	0.05
Oxygen(wt.%)	13	12	ND
Hydrogen(wt.%)	0	11	ND

ND: Not Determined

Table 3 exhibits the comparative study of T. bellirica methyl ester with diesel and standard biodiesel. Carbon composition of T. bellirica methyl ester (C_{12}-C_{22}) is in reasonable range of standard biodiesel. It has the specific gravity 0.9077 which is higher than standard value of diesel and biodiesel experiencing a lower level of atomization. The flash point 162^{0}C is too high than diesel which represents the higher combustion temperature requirement for proper and complete combustion due to the flash point close to the upper limit of the range of biodiesel. Cloud and pour point are 5^{0}C, 1^{0}C respectively directing the storage of T. bellirica biodiesel at a temperature above the standard value of diesel and biodiesel. The amount of carbon presence is not determined. Water is determined by volume percentage that is of about 0.07% which is also in a higher portion. Cetane number 53.4 is in the middle within the range of cetane number of standard biodiesel, which results a modified and reasonable hydrocarbon emission and noise levels accepting by the concerning authority. Also less sulphur indicates less sulphur related emission. The O_2 and H_2 amount in T. bellirica methyl ester are not determined.

Table 4 : Physiochemical properties of blends of T. bellirica biodiesel and diesel against IS 1460 standard

Test property	IS 1460 standard	Test method	Diesel	T. bellerica methyl ester blended with diesel at. %			
				5%	10%	15%	20%
Acidity, inorganic	Nil	IS 1448 [P:2]	Nil	Nil	Nil	Nil	Nil

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Acidity total, (mg KOH/g), max.	To report	IS 1448 [P:2]	0.015	0.02	0.05	0.07	0.09
Pour point, max. (a) Summer (b) Winter	 15°C 3°C	IS 1448 [P:10]	-12	-6	-6	-7	-9
Copper corrosion, max	Not worse than No. 1	[P:15]/ISO 2160	No. 1	No. 1	No. 1	No. 1	No. 1
Flash point Abel, °C, min.	35 °C	IS 1448 [P:20]	43	44	45	46	47
Kinematic viscosity (cSt) at 40 °C	2.0–4.5	[P:25]/ISO 3104	2.41	2.87	2.99	3.01	3.04
Density at 15 °C, (kg/m3)	820–845	IS 1448 [P:16]/ISO 3675	834.8	835.0	837.6	838.5	839.4
Water content, (mg/kg), max.	200	[P:40]/ISO 12937	<200	<200	<200	<200	<200

Reported by S. Rakesh., Meeta S., Arif A. K.(2010).

T. bellirica biodiesel was blended with diesel at 5%, 10%, 15% and 20% (v/v) dosages and tested for key physico-chemical properties as per IS 1460:2005 BS III Diesel specification and data are presented in Table 4. Blends of biodiesel with diesel were found to be completely miscible and gave stable mixtures. In table 4, it is noticed that by addition of biodiesel to diesel, the total acidity raises from 0.015 to 0.09 mg KOH/g. Kinematic viscosity and density values increases with increase in the concentration of biodiesel in the respective bends, while flash point of diesel gets marginally affected on blending up to 20% dosage, but remains within specified limit. Diesel water content was unaffected even up to 20% blending of T. bellirica biodiesel. The pour point of all the three blends was found in the range of 6 to 9°C meeting the specification limit. The diesel biodiesel blends were also found to be non-corrosive to copper.

d) Performance evaluation of T. bellirica biodiesel and DF blends

T. bellerica biodiesel was blended with diesel at 5% (BME 5), 10% (BME 10), 15% (BME 15) and 20% (BME 20) (v/v) dosages and its performance test was done in single cylinder peter diesel engine having the following specification.

Table 4 : Engine specification

Engine type	4- stroke CI engine
Number of cylinders	one
Bore * stroke	80*110 mm
Cooling	water cooling
Compression ratio	16.5
Rated power	4.476 Kw@1800 rpm
Injection pressure	14 Mpa (low speed, 900-1099 rpm) 20 Mpa (high speed, 1100-2000 rpm)0
Injection timing	24°BTDC

By varying rpm from 600 to 1250 rpm at load 55.6 N, maximum efficiency was obtained at 900 rpm. Every test was carried up to minimum five times for getting maximum reliable result.

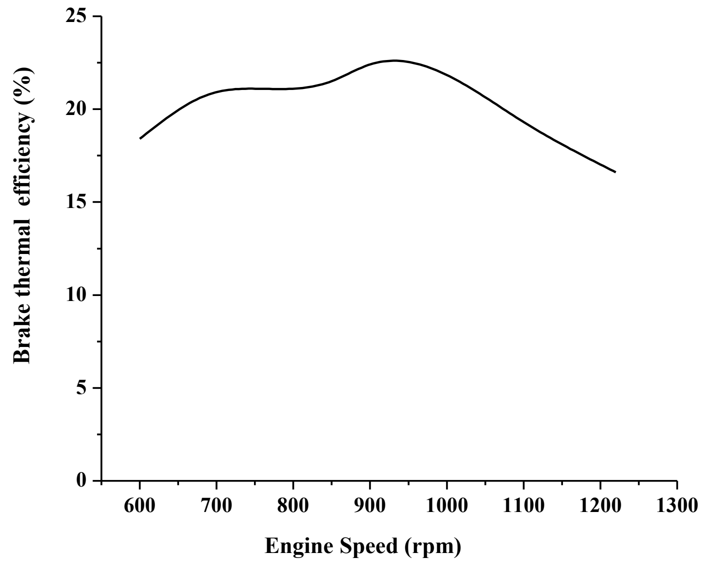

Figure 1 : Variation of brake thermal efficiency with engine speed (At load 55.6 N)

Figure 1 illustrates the variation of brake thermal efficiency with engine speed at load 55.6 N with diesel. From the figure it is seen that the brake thermal efficiency of engine increases with increase of engine speed. After reaching the maximum value, the efficiency of the engine also decreases. This is due to the fact that, initially with the increase of engine speed the torque produced by the engine increases, hence the efficiency also increases. But at higher rpm (>900) more amount of fuel is injected into the engine cylinder per cycle and due to higher engine speed these fuel doesn't get sufficient time to burn completely which reduce the efficiency of the engine. Hence the maximum efficiency obtained at 900 rpm.

Then the engine was run at the fixed rpm (900) and brake power was varied from 0.43 KW to 1.02 KW.

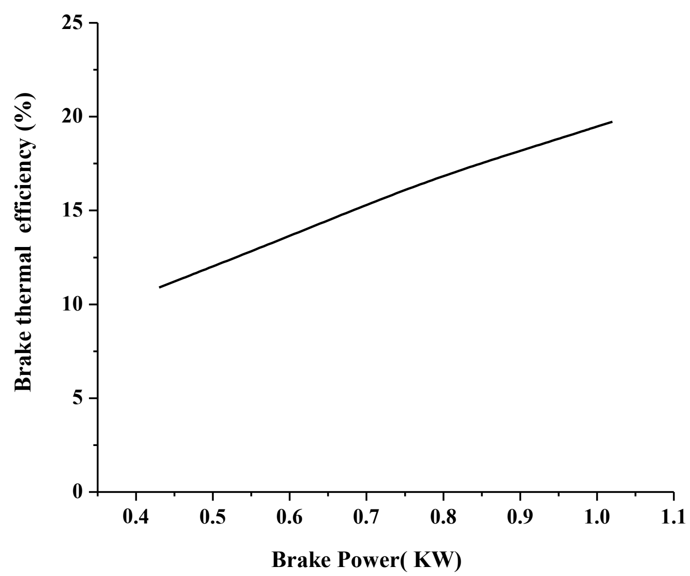

Figure 2 : Variation of brake specific fuel consumption with brake power (Engine speed 900 rpm)

Fig. 2 illustrates variation of brake thermal efficiency of engine with respect to brake power. It presents that the efficiency of the engine increases with the increase in brake power. The maximum brake thermal efficiency of diesel fuel is 22.86% at brake power 1.02 KW. Higher brake thermal efficiency is due to better mixing of fuel with air which results in better combustion. At higher brake power (> 1.02 KW) more amount of fuel is injected into the engine cylinder which not completely burned. It causes higher BSFC and low brake thermal efficiency. This drop in efficiency is due to the poor volatility, viscosity and density of diesel

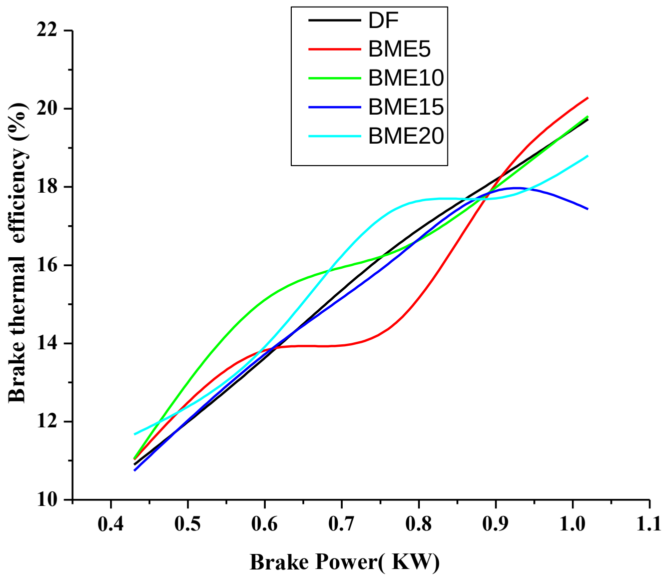

Figure 3 : Variation of brake thermal efficiency with brake power

Variation of brake thermal efficiency with brake power is illustrated in Fig. 3. From this figure it is observed that the brake thermal efficiency increases with the increase in engine load (brake power) for all fuels/ blends. It is interesting to note that compared to DF, BME 15 blends almost coincide with DF showing higher brake thermal efficiency than BME 5 and lower than BME 10 and BME 20. The maximum value of brake thermal efficiencies with BME 5, BME 10,BME 15, BME 20 blends and DF were found to be 20.29%, 19.81%, 17.94% , 18.8% and 19.73% respectively at brake power 1.02 KW.

Figure 4 compares the fuel consumption of diesel, blends of BME at various brake power in the range of 0.43 KW-1.02 KW. It can be seen from the figures that the BSFC decreases with the increase in engine brake power. It is interesting to note that the BSFC is lower with all BME blends relative to DF.

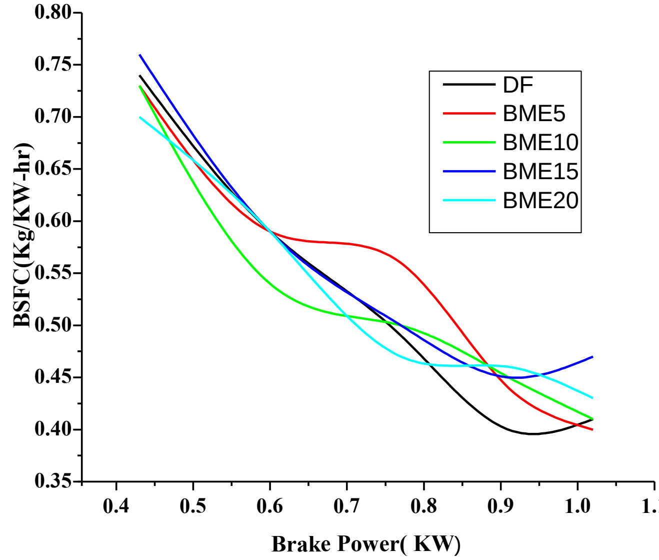

Figure 4 : Variation of brake specific fuel consumption with brake power

Brake specific energy consumption (BSEC) is lower with BME blends compared to DF. We know thermal efficiency is the reciprocal of fuel consumption and heating value. So that the brake thermal efficiency increases and BFSC decreases with the increase in engine load (brake power) for all fuels/blends. Thus, as the BSFC is lower with the BME blends the BFSC will also be lower with all BME blends the value of BFSC with BME 5, BME 10, BME 15, BME 20 blends and DF were found to be 0.40 kg/KW-hr, 0.41 kg/KW-hr,0.47 kg/kW-hr, 0.43kg/kW-hr and 0.413 kg/KW-hr respectively at brake power 1.02 KW. However, for the BME 5 blend, the fuel consumption was lower when compare to other blends of BME and DF, when the applied load was 1.02 KW. The DF100 had the highest specific fuel consumption. However, as the brake power of the engine increases the specific fuel consumption for all BME blends and diesel.

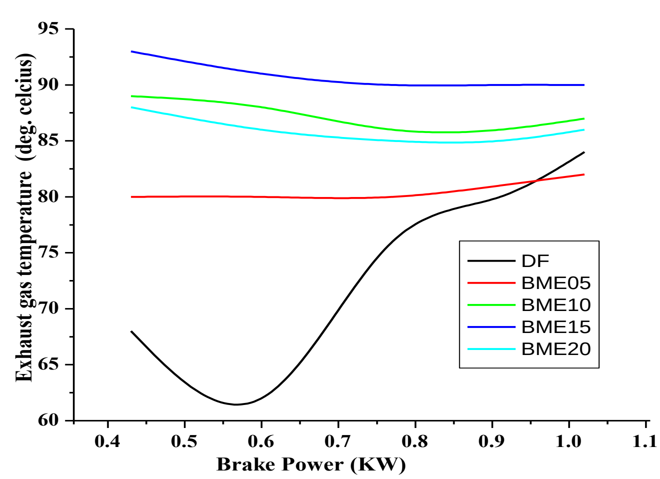

Figure 5 : Variation of exhaust gas temperature with brake power

A slight variation of exhaust gas temperature of various DF and BME blend is investigated in Fig. 5. The exhaust gas temperature of BME 5, BME 10, BME 15 and BME 20 are 82°C, 89°C, 93°C and 88°C respectively whereas diesel is 84oC. The reason is may be due to high auto ignition temperature for increase in exhaust gas temperature. Due to this, the heat that is generated due to the compression stroke gets shifted its direction toward the exhaust side and increases the exhaust gas temperature.

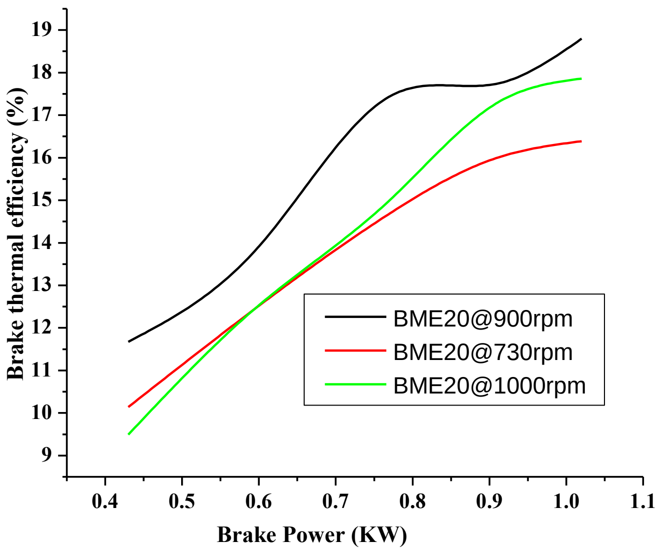

Figure 6 : Effect of BME on efficiency at low and high speed condition

Variation of thermal efficiency with brake power is illustrated in Fig. 6. From the above figure it observed that the brake thermal efficiency increases with the increase in engine load (brake power) for all fuels /blends. But relatively BME 20 at speed 900 rpm gives higher thermal efficiency because of proper combustion of fuels. Due to the fact that at higher speed and lower speed more amount of fuel is injected into the engine cylinder which is not completely burned so thermal efficiency lower.

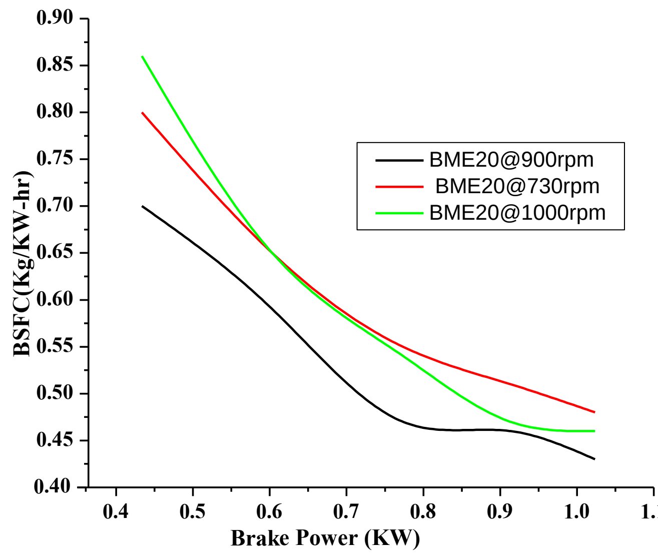

Figure 7 : Effect of BME on BSFC at low and high speed condition

Fig. 7 represents the variation of BSFC with brake power. Thermal efficiency is the reciprocal of fuel consumption and heating value, So that the brake thermal efficiency increases and BSFC decreases with the increase in engine load (brake power) for all fuels/blends. It is observed. At speed 900 rpm BSFC is lower because a minimum amount of fuel is injected into the engine cylinder which is completely burned. So BSFC becomes lower. On the other hand at low and high speed condition engine remain idle so BSFC is higher than that of optimum speed.

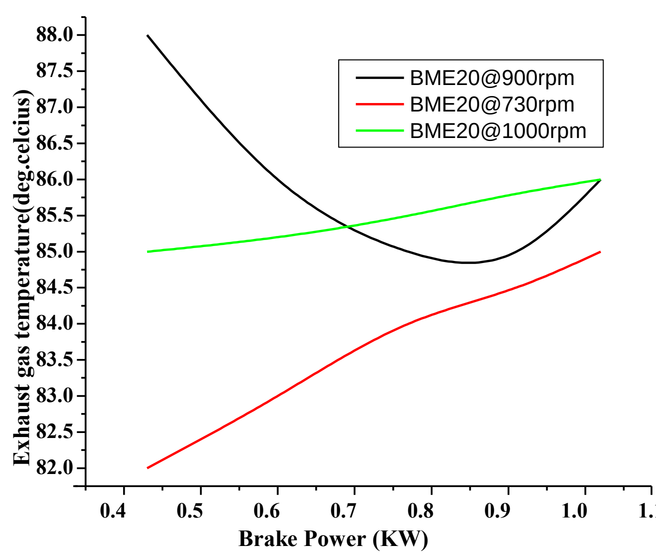

Figure 8 : Effect of BME on temperature at low and high speed condition

Fig. 8 shows the variation of exhaust gas temperature of various DF and BME blend. The exhaust gas temperature of BME 20 at speed 900 rpm is maximum. The reason is may be due to high auto ignition temperature for increase in exhaust gas temperature. At high or low speed the heat that is generated to the compression stroke is lower due to uncompleted combustion so less heat that is generated due to the compression stroke gets shifted its direction toward the exhaust side less.

IV. Conclusions

This work discusses the production of BME in Bangladesh, characterization of BME and its blends and the influence of its blends on diesel engine performance. All results were compared with those of DF. The results of this work were summarized as follows:

a) Bangladesh can reduce diesel import from foreign countries by 17% if Bahera is cultivated in the unused land of Bangladesh.
b) Production of T. bellirica oil and its biodiesel was done and properties were compared with other vegetable oils, biodiesels and pure diesel.
c) Compared to Jatropha oil, sunflower oil, Soybean oil and Rapeseed oil the viscosity, density, cloud point, pour point and oxidation stability are higher with T. bellirica oil. Rest of the physicochemical properties of tested T. bellirica oil was reasonable with those of other vegetable oil.
d) The acid number, viscosity, cloud point, pour point, density and glycerin content of T. bellirica methyl ester were higher compared to Jatropha and Sunflower methyl ester. The cetane number and flash point were lowered by a limited value of those properties.
e) The fuel properties of T. bellirica methyl ester were approximately similar to that of standard biodiesel. Whereas compared to pure diesel fuel properties of T. bellirica were varied in a considerable limit.
f) T. bellirica biodiesel was tested in a single cylinder, 4-stroke diesel engine. Compared to DF the brake thermal efficiency and BSFC with DF and BME blends were almost unchanged.
g) The results of above investigation revealed the possibility of T. bellirica as a potential source of biodiesel.

V. Acknowledgement

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The Modified Pyrolysis Process to Minimize the Energy Consumption by Preheating the Opaque Reactor using Solar Energy and Determination of Possibility in Case of using it in Diesel Engine

By Md. Tasruzzaman Babu, Md. Abdur Rahim & Md. Sohel Rana
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Abstract- This paper represents the difference between conventional process and modified process in pyrolysis technology. In this experiment it was tried to lessen the fuel cost and energy consumption using a parabolic solar collector, some side glasses and some magnifying glasses to concentrate sun beams and magnify the solar intensity for heating up the opaque reactor. The energy consumption in the conventional process was obtained as 9900000 J. The energy consumption obtained in case of modified pyrolysis process using solar energy was 7290000 J. Hence, the energy consumption was lessened by modified process by 26% than the conventional process. Here physical analysis of obtained oil has also been shown to determine the possibility of using it in diesel engine.

Keywords: pyrolysis; biomass oil; diesel; preheating.

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I. Introduction

A reliable, affordable and clean energy supply is of major importance for society, economy and the environment- and will prove to be crucial in the 21st century. In this context modern use of biomass (as opposed to traditional use) is considered very promising. The promise includes a widely available, renewable and CO_2-neutral resource, suited for modern applications for the power generation, fuels and chemicals. Biomass has a distinct advantage over the use of other renewables, like solar cell and wind power, which are restricted because of the intermittent power generation. Biomass is by far the most applied renewable at this moment and a further increase is believed to be possible [1].

The standard of living and quality of life of a nation depend on per capita energy consumption. Bangladesh is a developing country, and is one of the most populated (914 persons/km^2) countries in the world. Her per capita energy consumption in 2005 stands at 227 kgOE (kilograms of oil equivalent), which is much below the world average of 1778 kgOE. The energy consumption mix was estimated as: indigenous biomass 60%, indigenous natural gas 27.45%, and imported oil 11.89%, imported coal 0.44% and hydro 0.23% [2] More than 76% of the country's population lives in rural areas, meeting most of their energy needs from traditional biomass fuels. Around 32% have access to electricity, while in rural area the availability of electricity is only 22%. Only 3-4% of the households have connection of natural gas for cooking purposes. Only about 2-3% households use kerosene for the same purpose and the rest (over 90%) of people depend on biomass for their energy needs [3]. Due to mitigate the large demand of electricity, there are lots of power plants established every year in Bangladesh. Most of the power plants are steam based. So, a large amount of furnace oil is required for running a boiler. Pyrolysis oil can be used both as furnace oil and fuel oil for cooking purpose. Pyrolysis oil has been successfully tested in engine, turbines and boilers, and been upgraded to high quality hydrocarbon fuels although at a presently unacceptable energetic and financial cost. Thus, it is crucial to find out alternative and sustainable resources such as pyrolysis oil to mitigate the energy crisis in Bangladesh.

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II. Pyrolysis and its Chemical Reaction

Pyrolysis is an attractive method to recycle scrap tires has recently been the subject of renewed interest. Pyrolysis of tires can produce oils, chars, and gases, in addition to the steel cords, all of which have the potential to be recycled. Tire pyrolysis liquids (a mixture of paraffins, olefins and aromatic compounds) have been found to have a high gross calorific value (GCV) of around 41-44 MJ/kg, which would encourage their use as replacements for conventional liquid fuels [4, 5, 6]. In addition to their use as fuels, the liquids have been shown to be a potential source of light aromatics such as benzene, toluene and xylene (BTX), which command a higher market value than the raw oils [7, 8]. Similarly, the liquids have been shown to contain monoterpenes such as limonene [1-methyl-4-91-methylethenyl)-cyclohexene] [9, 10].

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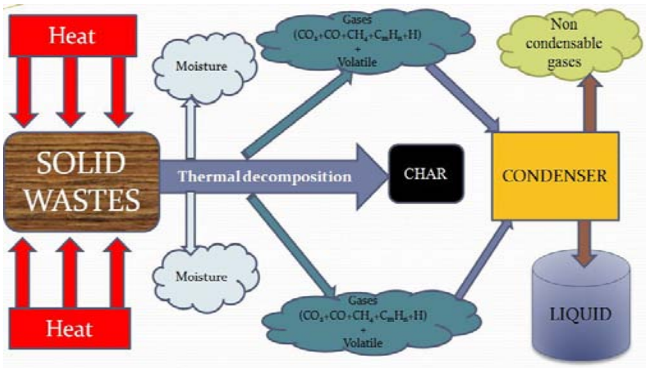

Figure 1 : Thermal decomposition of organic solid wastes

Pyrolytic char may be used as a solid fuel or as a precursor for the manufacture of activated carbon [11, 12]. It was found that another potentially important end use of the pyrolytic carbon black (CBp) may be as an additive for crude bitumen [13]. Some of the previous research group studied the composition of evolved pyrolysis gas fraction and reported that it contains high concentration of methane, ethane, butadiene and another hydrocarbon gases with a GCV of approximately 37 MJ/m^3, a value sufficient to provide the energy required by the pyrolysis process [14].

Table 1 : Proximate and elemental analysis of solid waste tires [15]

Proximate analysis (wt %)		Elemental analysis (wt %)	
Moisture	0.82	Carbon (C)	80.30
Volatile	62.70	Hydrogen (H)	7.18
Fixed carbon	32.31	Nitrogen (N)	0.50
Ash	4.17	Oxygen (O)	8.33
H.C.V (MJ/kg)	33.30	Others	3.69

Pyrolysis can be presented by the following equation

$$CaH_bO_c + Heat \longrightarrow H_2O + CO_2 + H_2 + CO + CH_4 + C_2H_6 + CH_2O + \ldots\ldots\ldots + Tar(liquid\ oil) + Char$$

The three classes of products of pyrolysis, then, are volatiles, tar and char.

Table 2 : Thermochemical conversion technologies, products and application

Technology	Primary product	Example of application
Pyrolysis	Gas Liquid Solid char	Fuel gas Liquid fuel and chemical Solid fuel or slurry fuel
Liquefaction	Liquid	Liquid fuel substitution
Gasification	Gas	Fuel gas
Combustion	Heat	Heating

III. Pyrolysis Technology using an Opaque Reactor Preheated by Solar Energy

Though pyrolysis is not a new technology in this modern age, it is not so familiar yet using solar energy especially in case of opaque reactor. Some works have been carried out using transparent reactor made of glass implementing green house effect. But these are not suitable for mass production as the reactors made of glass cannot carry much load. To solve this problem an

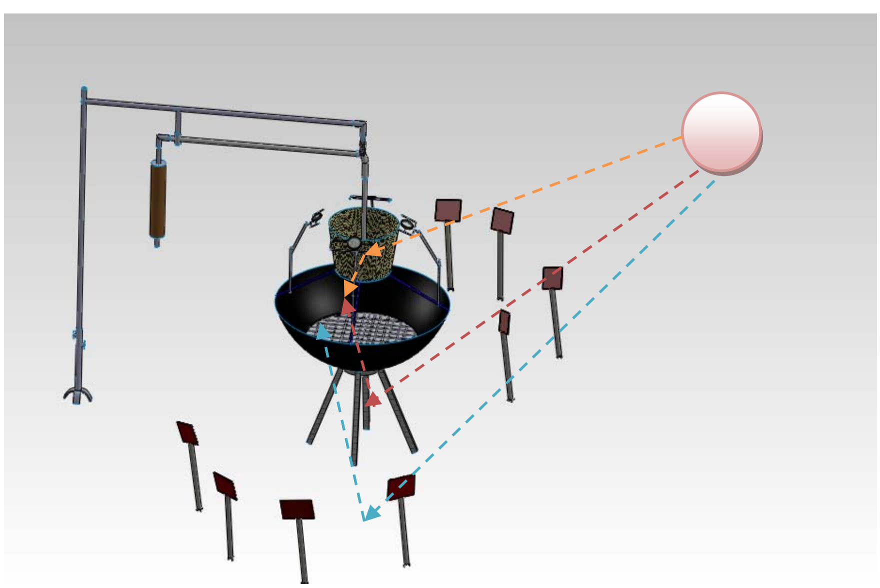

Figure 2 : Methodology of Preheating

Figure 3 : Experimental Setup of Preheating

Figure 4 : Experimental Setup of Heating by Electrical Heater

experiment on 'The modified pyrolysis process to minimize the energy consumption by preheating the opaque reactor using solar energy and determination of possibility in case of using it in diesel engine' has been carried out in the month of July, 2013 in Rajshahi University of Engineering & Technology (RUET), Bangladesh.

Feed tire Pyrolytic oil Char

Figure 5 : Feed tire, Pyrolytic oil obtained by our process and Cha

IV. Working Procedure

a) With the Preheated Reactor by Solar Energy

- The reactor was poured with desired amount of biomass products (tyre).
- Then the atmosphere into the reactor was made inert with the aid of nitrogen.
- The reactor was heated up to 112°C with solar energy which was concentrated by the parabolic solar collector, magnifying glasses and side glasses also.
- After that the reactor was heated up to 285°C using fuel using electric heater. At this moment pyrolysis was started. Then the temperature was increased up to 350°C.
- The gaseous products after burning were condensed into the condenser using condensing water.
- The nitrogen gas was supplied within a regular interval so that burning could not take place into the reactor.
- After condensing, the oil was gotten with some portion of flue gases which were burnt for the safety of atmosphere.
- After burning the solid product (char) was gotten in the reactor.
- After finishing the tire pieces into the reactor completely, new tire pieces were fed again to continue the process.

b) Without using Solar Energy

In this case, similar process from (d to i) were done again and two processes were compared.

c) Calculation of the Average Value

Similar operations were performed for 3 times for both partially using solar energy and without using solar energy to calculate the average value.

Energy consumed =81*60*1500 J

=7290000

Save for 9900000 J is (9900000-7290000) J

Save for 100 J is (9900000-7290000)*100/9900000 J

=26.36J

So, the save is 26.36 %

i. *For the Second Observation*

Similarly the percentage of saving is 25.79

ii. *For the Third Observation*

Similarly the percentage of saving is 25.29

Hence, the average saving of energy is 26%.

VI. Result and Discussion

a) Result

The average saving of energy is 26%.

b) Discussion

There are various graphs shown below to describe the relation among various parameters and these are also drawn to express the reasons of their relations.

V. Calculation

For the first observation

Ambient temperature=40.5°C

Amount of feed material =500gm

Amount of pyrolysis oil=190gm

a) Pyrolysis Without Solar Energy

Total working time =110 minutes

Energy consumed =110*60*1500 J

=9900000 J

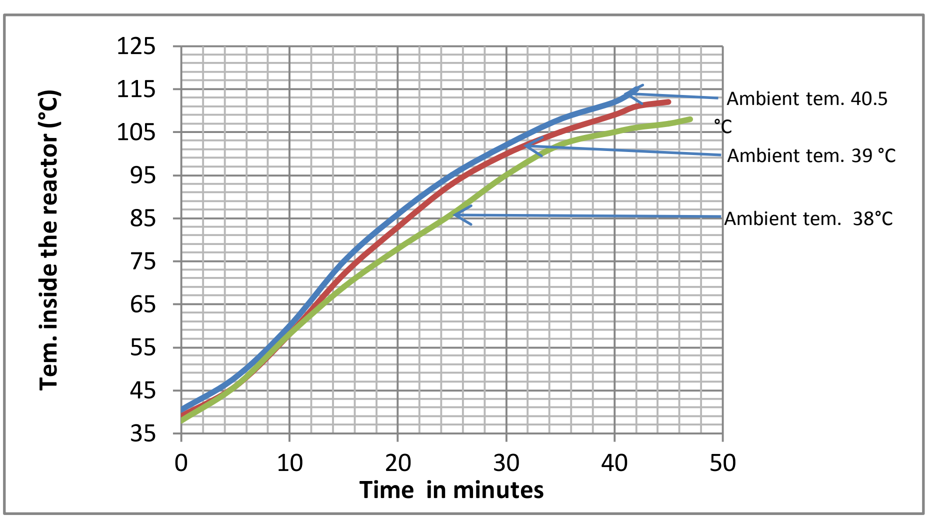

Figure 6 : Time vs Temperature curve inside the reactor

Since in case of preheating the temperature inside the reactor is increased with the increase of ambient temperature at approximately proportional rate. And at the initial time the temperature inside the reactor is same with the ambient temperature. For this reason it starts with a certain initial temperature which is equal to the ambient temperature. When the ambient temperature is comparatively higher then increasing temperature inside the reactor was also higher than other.

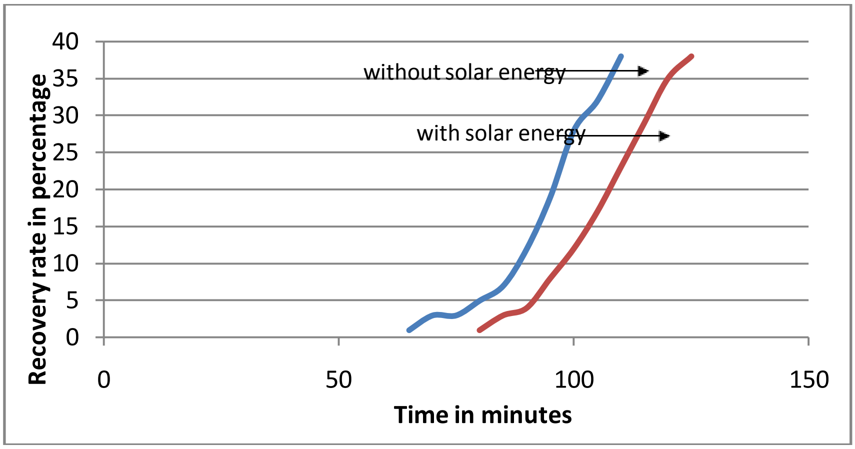

Figure 7 : Time vs recovery rate curve

Since the recovery starts at a certain temperature, in case of solar energy this certain temperature is obtained after sometimes comperatively to the conventional process. But after getting this temparatrure with the help of electrical energy the recovery rate is approximately same and for this reason the curves patterns are also approximately same.

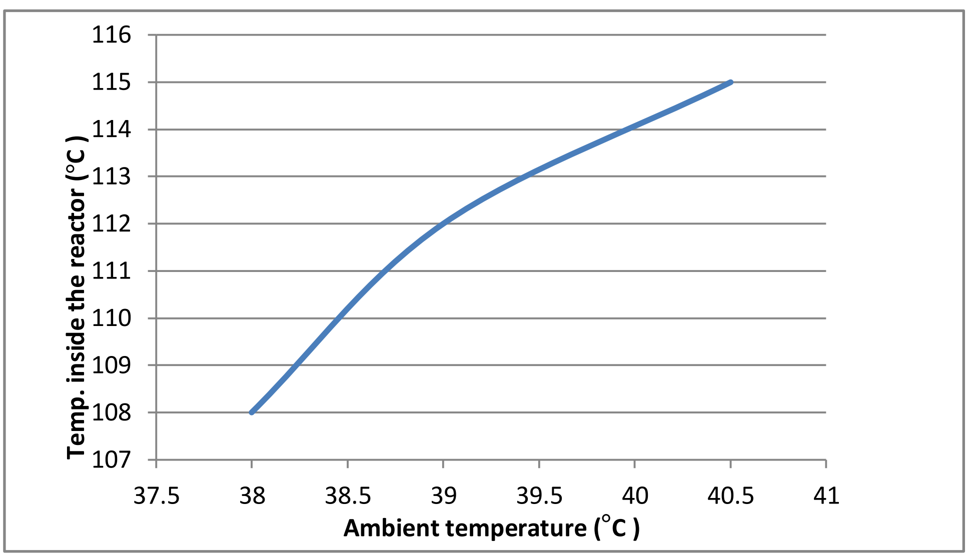

Figure 8 : Ambient temperature vs temperature curve inside the reactor

Since temperature inside the reactor is a proportional function with the ambient temperature up to a certain range and after that the increasing rate is lower than previous increasing rate, the curve is like to that pattern.

Table 3 : Physical characteristics of tire pyrolysis oil after some treatments and its comparison with diesel

Analysis	Tire pyrolytic oil	Diesel [16]
Kinematic viscosity at 35^{0}C (cSt)	3.1	2.61*
Density (kg/m^3)	920	827.1*
Flash Point (^{0}C)	56	53
HHV(MJ/kg)	42.24	45.18

*at 20^{0}C

VII. Conclusion

Experimentally it has been seen from result that the cost and energy was saved by 26 % approximately than the conventional process. That contains a good probability to make more profit. And this process may become more attractive commercially and beneficial in the developing countries. From the comparison in table 1, it is seen that the properties of tire pyrolysis oil obtained by authors are quite similar to diesel. That is why, there is a great possibility to use tire pyrolytic oil as an alternative of diesel. Though obtained properties of tire pyrolytic oil are comparatively lower than diesel, but if some treatments are taken then it will be useful as diesel. That will be helpful to meet the demand of fossil oil in future. Though treatment may increase the oil cost than diesel but it will be beneficial when mass production will taken.

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Nomenclature

BTX	benzene, toluene and xylene
CBp	pyrolytic carbon black
GCV	gross calorific value
HHV	higher heating value
kgOE	(kilograms of oil equivalent)

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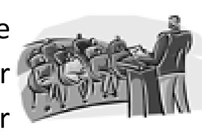

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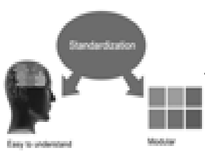

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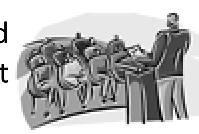

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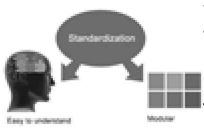

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- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
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Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
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Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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