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# THE CFD INVESTIGATION OF FLASH DRYER AND ROTATING KILN DESIGN

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## ABSTRACT

The retorting or heating of oil-shale particles has been modelled using Fluent CFD code. The hydrocarbon component is an organic solid which can be liberated by the application of heat, in order of 500°C. A number of processes have been modelled in this study. A rotary kiln consisting of a horizontal rotating cylindrical vessel has been modelled. The mixing process of the oil-shale and retorted oil-shale particles in an Eulerian-Eulerian basis and the flash drying process of oil-shale and coal particles in a Lagrangian approach are studied here. Further study would look at oil-shale pyrolysis and combustion of remaining carbon on the shale.

## INTRODUCTION

CFD has increasingly been used to address multi-phase flows occurring in many industrial applications such as cyclone separators, electrostatic precipitators, pneumatic conveyors and fluidised bed combustion. The increased use has been motivated by significant improvements in the capabilities of various commercial CFD codes and major reduction in the cost of computer hardware.

Much of the multi-phase flow problems involved dilute solid phase in which the conventional Lagrangian approach could be used to trace particles individually. A two-way coupling approach, in some cases, is sometimes used to consider mutual particle-fluid interactions. For dense solid phase flows, Eulerian approach needs to be used in order to account for particle-to-particle as well as fluid-fluid and particle-fluid interactions. As can be expected, computation times have been much longer with this approach. The Lagrangian approach might become computationally expensive if stockasting tracking of particles in a two-way coupling scheme is investigated. However, availability of cheaper computers with large memory and much faster processing speed and advances in CFD capabilities have recently allowed Eulerian and Lagrangian approaches to be used in many industrial applications.

In this paper, we present initial results in using the above two approaches as applied to flash dryer and rotating solid mixers designs using Fluent CFD software. Lagrangian approach has been used in modelling the drying process of both coal and oil-shale particles in a lift-pipe type column. As the second part of this investigation a 3D rotating mixer has been modelled based on Eulerian approach to investigate mixing process of raw oil shale particles and recycle combusted shale in a proposed rotating kiln type retort.

## PROBLEM DESCRIPTION

The technology of using oil shale particles to generate oil was developed by William (Bill) Taciuk from UMATAC Industrial Processes and financially supported by AOSTRA - Alberta Oil Sands Technology and Research Authority. The processor is called AOSTRA Taciuk Processor - ATP. The rotary kiln is the base of the ATP design based on four steps processing:

1. Preheat of shale
2. Oil shale pyrolysis
3. Combustion of remaining carbon on the shale
4. Heat recovery from the hot, combusted shale

Figure 1 and 2 show how the ATP works. The shale is fed to the preheat tube. The temperature here increases to 250°C. Through a seal it is then sent to the retort zone. The temperature reaches 500°C. At this stage the hydrocarbon vapour is generated which is drawn out and condensed to a liquid. The remaining retorded shale is transferred to the combustion zone and is burnt to raise its temperature to 750°C. The hot combusted shale is then mixed with the preheated feed. This mixing produces the reaction temperature in the retort.

## THE MODELLING APPROACH

Three different cases are studied here as the following:

1. The mixing process in rotating retord
2. The flash dryer of oil-shale
3. The flash dryer of coal particles

The first one is modelled using Eulerian-Eulerian approach, which solves the momentum, continuity and species for each phase (Anderson and Jackson, 1967 and Bowen, 1976). Coupling is achieved through the pressure and exchange coefficients. The flash dryer cases are based on Lagrangian approach. The trajectory of oil-shale or coal particles are modelled by integrating the force balance in a two-way coupling approach.
In terms of boundary conditions, a polynomial wall velocity is applied to the rotating drum. For the granular viscosity the Syamlal-O'Brien model, 1989, is used which has shown to be the appropriate model for granular flows. Due to the small rotating speed of the drum the mixture flow is taken to be laminar.

## RESULTS AND DISCUSSION

### *Solid Mixing in the Retort*

Mixing of solids in the retort was simulated up to more than 400 seconds, which is about twice the time it takes to fill an initially empty retort to a level that solids flow out of the retort exit. Instantaneous results at about 360 seconds are presented in Figures 3 and 4 as contour plots of volume fractions of shale and recycle shale at various K and I slices. Note that the scale of the axis is the same for all cases with a maximum of 4m/s for velocity and 0.6 for volume fraction. This allows easier comparison of the results.

Contour plots of volume fractions of raw oil shale and recycle shale for various K and I slices show that:

- Solids close to the wall of the retort were mainly recycle shale especially on the side of recycle shale inlet. This suggest possible inadequate mixing of raw oil shale and recycle shale.
- Mixing of incoming raw oil shale with the bulk of the solids occurred mainly on the side opposite that of the recycle shale inlet.
- Recycle shale accumulated at the end of the main section of the retort. This is another possible indication of inadequate mixing which tends to reduce effective volume of the retort.
- Some degree of back-mixing was indicated by the presence of fairly large concentration of recycle shale upstream of recycle shale inlet. This could be a positive effect and likely to be enhanced in the actual retort due to periodic disturbance of the bed by the solids inlet port.
- Highest velocities (up to about 4m/s) occurred where the shale enters the retort and at the recycle shale inlet.
- Velocities near the wall were lower than those near the centre.

### *Heating and Drying of Raw Oil-Shale in a Flash Dryer*

Contour plots of velocity and temperature of gas and particle concentration are presented in Figures 5 and 6 for the converged solution. Trajectory of top-size (8mm) particle is shown as an example in Figure 7. Extent of drying for assumed values of particle diffusivities and other results are summarised in Table 1.

In general, gas with a velocity of 15 m/s at 1023K and 1 atm could entrain particles with sizes up to 8mm in the hypothetical design of shale flash dryer.

Contour and particle trajectory plots in the figures 5, 6 and 7 clearly show that:

- For up to more than half-way the length of the vertical column, entrained particles stayed close to one side, the side of solids inlet.
- Fairly high concentration of particles occurred close to the particle injection zone and at the top of the column.
- All particles hit the column top and some bounced several times before exiting the dryer.

All these results suggest that particle injection may need to be located closer to the centre so the gas could disperse them quickly across the column. When this is done, gas velocities lower than 15 m/s could be adequate for the given solids loading.

### *Heating and Drying of Coal in a Flash Dryer*

Rapid drying of coal particles is used as part of the retort oil shale processing system. The 3D grid, contour plots of velocity and temperature of gas are presented in Figures 8, 9 and 10 for the converged solution of coal drying process. A summary of simulation results for coal flash dryer is presented in Table 2. Case with finer grid showed similar exit gas temperatures and proportion of particles escaping the dryer via exit. It, however, predicts lower particle size. The 3D case gave a much lower fully entrained particle size and less particles escaping. In general, gas with a velocity of 25 m/s at 805K and 1 atm could only entrain about 70% of incoming particles in the proposed design of coal flash dryer based on heating mode only. With drying, this proportion appeared to increase by about 10%, possibly due to additional gas (steam from particles). Increasing gas velocity to 30m/s could further ensure all particles being entrained in drying mode based on a 2D model. However, amount of moisture removed decreased as may be expected due to shorter residence times of the particles in the dryer. Being similar in design, shale and flash dryer showed similar behaviour as shown in the contour and particle trajectory plots.

| **Particle Diffusivity ($m^2$/s)** | **Average exit particle T(K) for a given particle size** | **Particle residence time (s)** | **Average exit gas T (K)** | **Moisture removed (%)** |
|---|---|---|---|---|
| $1.2e^{-7}$ | 553 (0.025mm)<br>565 (4.0mm)<br>455 (8mm) | 5<br>11<br>8.4 | 571 | 10.6 |
| $3e^{-5}$ | 430 (0.025mm)<br>356 (4.0mm)<br>485 (8mm) | 4.8<br>11<br>16.6 | 416 | 40.9 |

**Table 1**: Summary of results for oil shale flash dryer simulation.

| | **Average exit particle T(K) for a given particle size** | **Particle residence time (s)** | **Particles escaped (%)** | **Average exit gas T (K)** | **Moisture removed (%)** |
|---|---|---|---|---|---|
| Heating only<br>2D coarse grid<br>25m/s gas | 689 (0.025mm)<br>552 (5.0mm) – max escaped<br>635 (8mm) – max lifted | 1.6<br>7.6<br>16.6 | 72 | 652 | NA |
| Heating only<br>2D fine grid<br>25m/s gas | 658 (0.025mm)<br>625 (4.0mm) – max escaped<br>609 (4.7mm) – max lifted | 1.4<br>10<br>11 | 69 | 655 | NA |
| Heating only<br>3D coarse grid<br>25m/s gas | 673 (0.025mm)<br>647 (3.3mm) – max escaped | 3.7 | 56 | 664 | NA |
| Drying<br>2D coarse grid<br>Diff=$3e^{-5}$ $m^2$/s<br>25m/s gas | 643 (0.025mm)<br>364 (4.6mm) – max escaped<br>364 (5.2 mm) – max lifted | 1.6<br>8<br>6.7 | 82 | 552 | 91.1 |
| Drying<br>2D coarse grid<br>Diff=$3e^{-5}$ $m^2$/s<br>30m/s | 680 (0.025mm)<br>364 (6mm) – max escaped | 1.7<br>6.7 | 100 | 593 | 87.4 |

**Table 2**: Summary of results for coal flash dryer simulation.

## CONCLUSION

Simulations of the following models were successfully completed using Fluent:

- 3D Eulerian-granular model of cold mixing of 1mm raw oil shale particles and 0.5mm recycle combusted shale in an AOSTRA Taciuk retort rotating at 4 revolution per minute with a nominal output of 55 tonnes per hour
- 2D and 3D Lagrangian models of entrainment of multi-size coal particles with and without drying in a 19m long lift-pipe column having a diameter of 0.84m
- 2D Lagrangian model of entrainment of multi-size oil shale particles with and without drying in a 19m long lift-pipe column having a diameter of 1.5m

Some of the interesting insights that these CFD simulations provided were as follows:

- Mixing of solids in the retort would appear to be inadequate.
- Some degree of back-mixing of recycle shale in the retort was indicated by the presence of significant concentrations of recycle shale upstream of recycle shale inlet.
- A gas velocity of 15 m/s (at 1023$^o$K and 1 atm) would appear to be too high in the shale flash dryer as all particles hit the top of the column.
- For the proposed design of coal flash dryer, a gas velocity of 25 m/s (at 805$^o$K and 1 atm) failed to entrain all of the particles. However, all particles were entrained at a gas velocity of 30 m/s.
- Based on assumed particle diffusivities, 10 to 40% of the moisture in the wet shale could be removed in the flash dryer. Two or more stages of drying may therefore be required to achieve complete drying.
- Based on assumed particle diffusivities, coal particles that were entrained were almost completely dried in the proposed design at a gas velocity of 25 m/s. However, moisture removal decreased when gas velocity was increased to 30 m/s as a result of lower particle residence times.
- The method of particle injection into the flash dryer may need to be improved as high concentrations of particles were observed close to the particle injection zone with both coal and shale. Moreover, entrained particles stayed close to solids inlet side more than halfway up the lift-pipe column.

The limited study that was undertaken has indicated that further modelling should consider:

- Refining the grid in both the retort and flash dryer geometries to check whether a grid-independent solution has been achieved. Solution adaption in Fluent/UNS, which currently does not have Eulerian-granular (dense phase) models, could also be applied in studying the solids inlet zone and various bends along the column of the flash dryer, as densities close to the point of injection exceeded recommended limits for Lagrangian (dilute-phase) models.
- Heat transfer and pyrolysis as well as coking/cracking reactions in the retort to fully assess this type of reactor.
- The effect of recycle shale solids inlet port which in an actual retort is fixed on the wall and extends beyond the wall boundaries, sweeping the bed periodically and therefore significantly affecting bed mixing near the inlet. Unfortunately, the Eulerian-granular model currently cannot be used to model this effect. One approach is to consider the secondary phase (particle) as a pseudo-fluid phase and apply a Eulerian-Eulerian model and sliding mesh technique. This will require an equivalent particle phase viscosity be initially determined experimentally or established through a series of Eulerian-granular modelling.
- Different methods of introducing solids to the flash dryer with the aim of dispersing the particles more evenly right near the bottom of the column.
- Effect of parameters such as gas and solids flows and other conditions that could impact on the operation of both the retort and the flash dryer.

## REFERENCES


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SYAMLAL, M., O'BRIEN, T. J., (1989), "Computer simulation of bubbles in a fluidised bed", *AIChE Symp. Series,* **85,** 22-31.

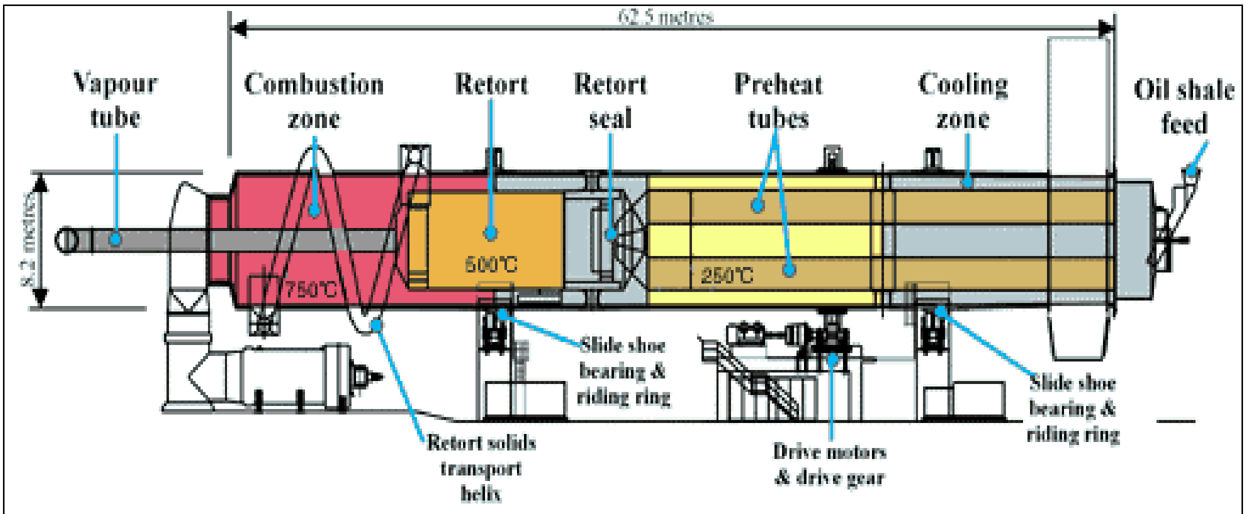


**Figure 1:** Cross Section of ATP

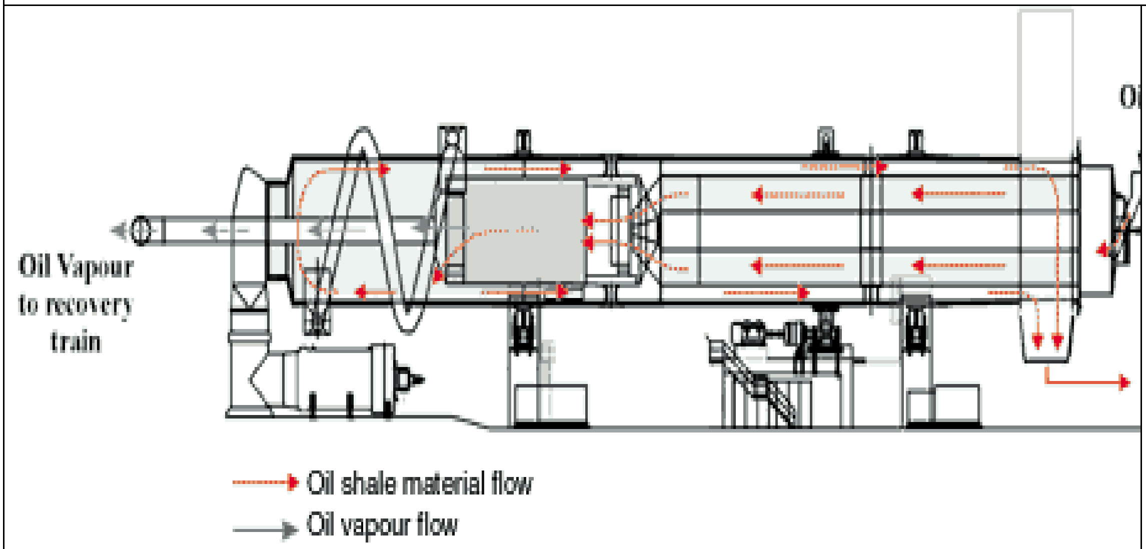


**Figure 2:** Material Flow through the ATP

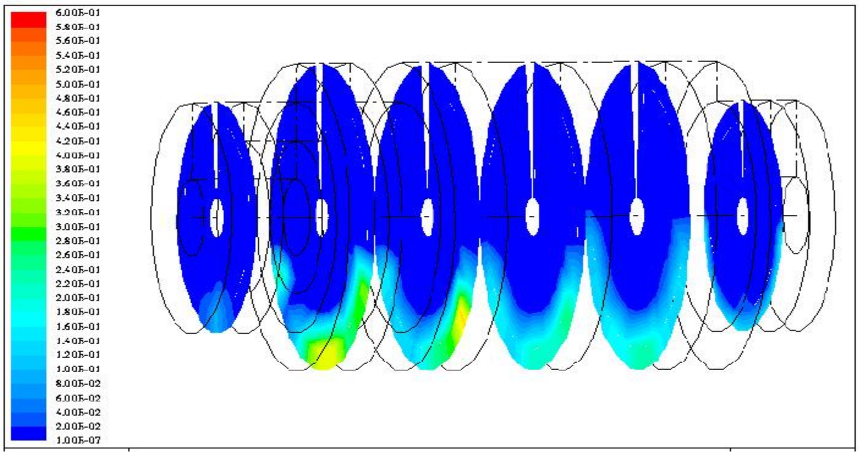

**Figure 3:** Oil Shale Volume Fraction

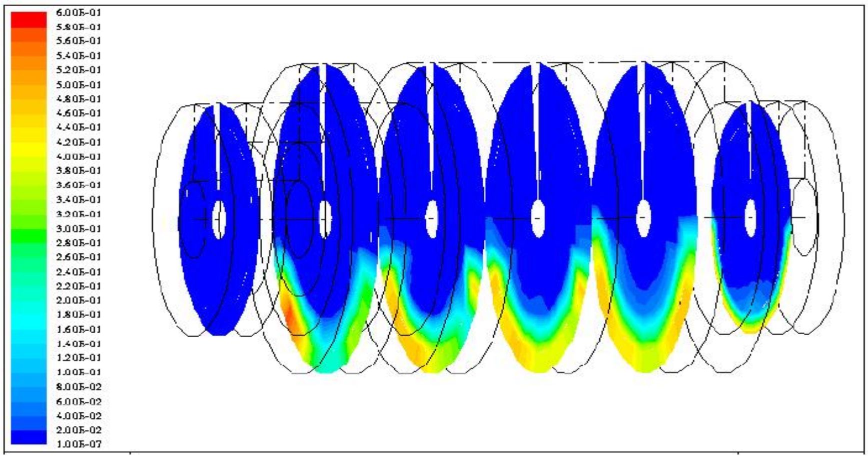

**Figure 4:** Retort Shale Volume Fraction

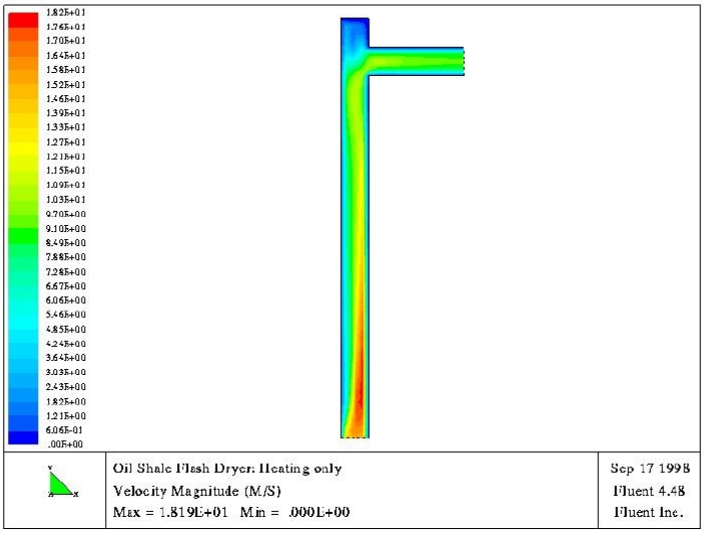


**Figure 5:** Velocity Contours

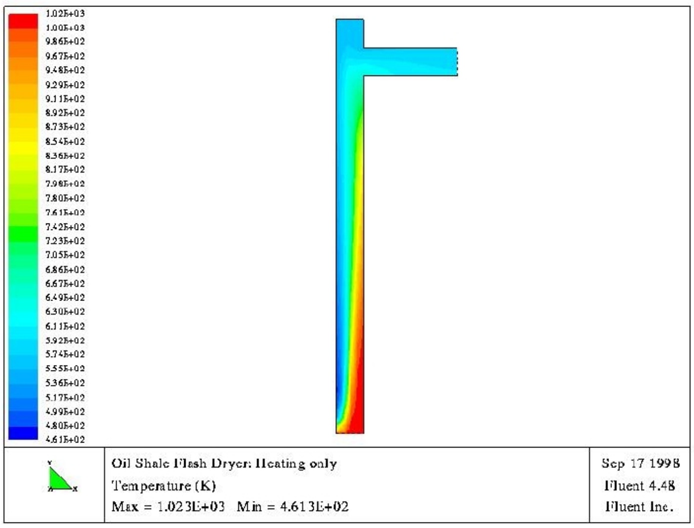


**Figure 6:** Temperature Distribution

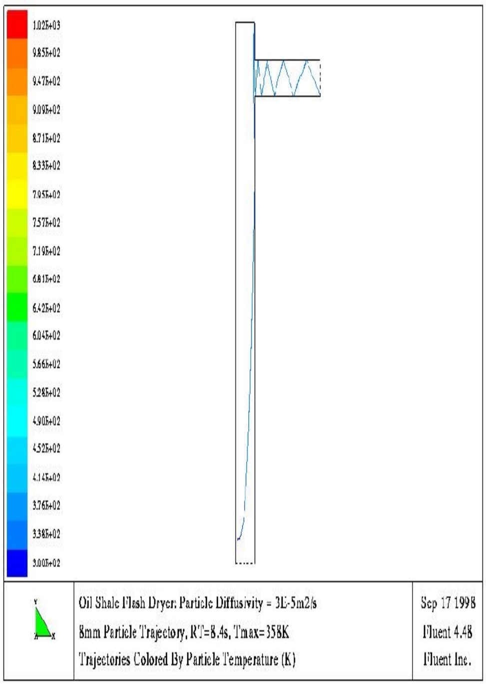


**Figure 7:** Oil Shale Trajectories

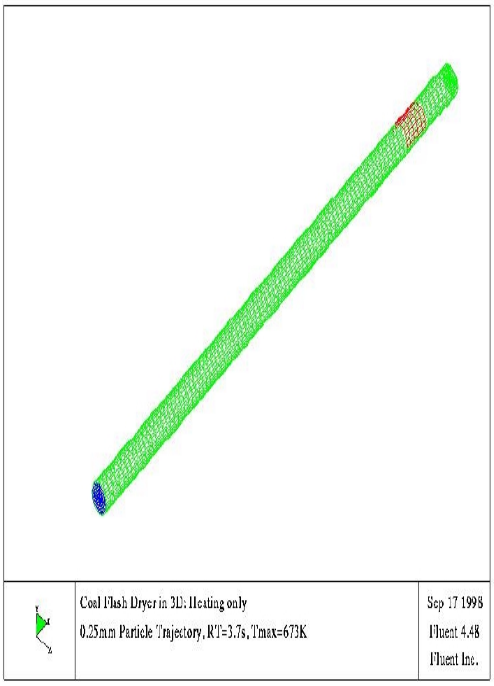


**Figure 8:** The Grid for Coal Drying Modelling

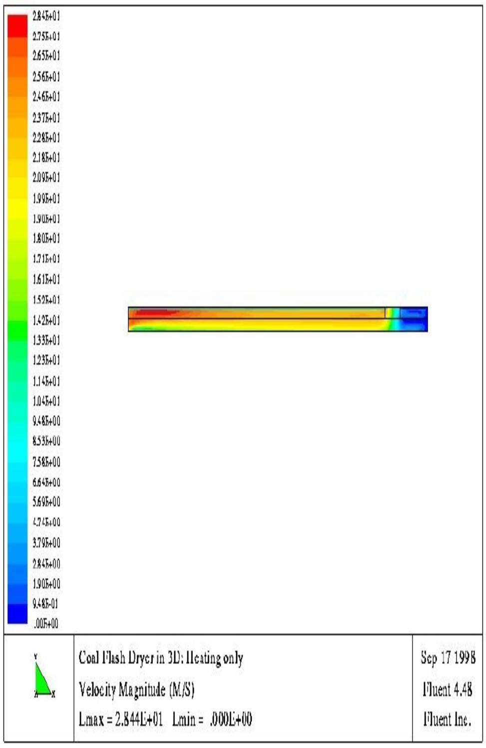


**Figure 9:** Velocity Contours of Coal Particles

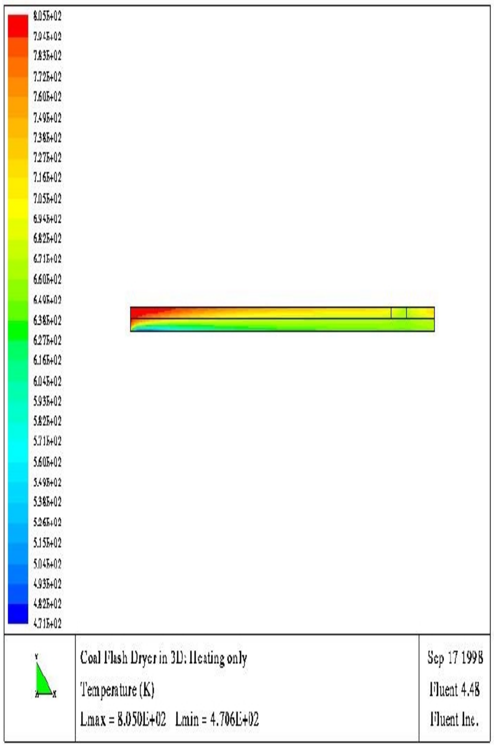


**Figure 10:** Temperature Distribution of Coal Particles