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# Analysis of Multi Gating System Using Computational Fluid Dynamics

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***Abstract:***
*Casting is a manufacturing process for making complex shapes of metal materials in mass production. There are two main consecutive stages; they are filling process and solidification process. Casting process design is important for production quality and efficiency.*
*Casting quality is heavily dependent on the success of gating system design, which currently is conducted mainly relied on technician's experience. Therefore there is need for the development of a pro-e tool with CFD (Computational Fluid Dynamics) Simulation and Optimization functions to ensure the quality of casting*
*The objective of the paper is to optimize gating systems based on Pro-e and simulation technology with the goal of improving casting quality such as reducing incomplete filling area, decreasing large porosity and increasing yield in this paper we have conducted the modular experimental setup for studying the flow of liquid in a multi-gate gating System. It consists of a pouring basin, a tapered sprue of square cross section, a runner of constant square cross section and four gates of same area of different cross sections i.e. rectangle, trapezoidal and compared the values with the CFD results obtained.*

## 1. Introduction

Casting is a manufacturing process for making complex shapes of metal materials in mass production. There are two main consecutive stages, filling process and solidification process, in casting production. In filling process gating system composed of pouring cup, runner, sprue, sprue well and ingate, is designed to guide liquid metal filling. Riser system is used to compensate shrinkage caused by casting solidification. Casting process design is important for production quality and efficiency.

It is unavoidable that many different defects occur in casting process, such as porosity and incomplete filling. How to improve the casting quality becomes important. Casting quality is heavily dependent on the success of gating/riser system design, which currently is conducted mainly relied on technicians' experience. Therefore there is a need for the development of a Pro-e tool with Computational Fluid Dynamics Simulation, and optimization functions to ensure the quality of casting.

The objective of the project presented in this thesis is to optimize gating/riser systems based on Pro-e and simulation technology with the goal of improving casting quality such as reducing incomplete filling area, decreasing large porosity and increasing yield.

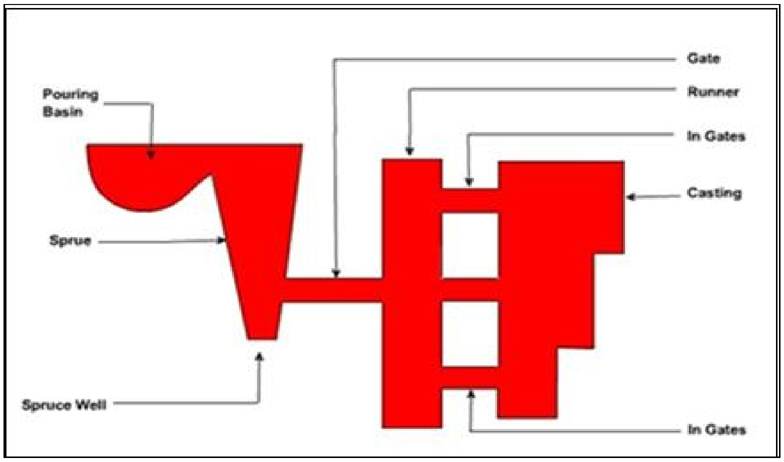


*Figure 1: Schematic of Gating*

Therefore in the thesis, a Pro-e and CFD simulation technology based optimization framework is presented. Given a Pro-e model of part design and after its being converted to casting model, the first objective is to evaluate discharge of each gate. Then runner and risers are presented parametrically. By varying each parameter, all Pro-e Models will be obtained. After analyzing simulation results, the original gating system design will be optimized to improve casting quality.

## 2. Experimental Details

### *2.1. Design of Gating System*

The assembly of channels which facilitates the molten metal to enter into the mold cavity is called the gating system. Alternatively, the gating system refers to all passage ways through which molten metal passes to enter into the mold cavity. The metal flows down from the pouring basin or pouring cup into the down gate or sprue and passes through the cross gate or channels and ingates or gates before entering into the mold cavity.

### *2.2. Gating Elements*

#### 2.2.1. Gating Ratio

Gating ratio is the area of sprue choke area to runner and ingates of gating system. In this problem we have gone for un-pressurized gating ratio is 1:2:1.5.

#### 2.2.2. Sprue Design

The sprue should be tapered down to take into account the gain in the velocity of the metal as it flows down reducing the air aspiration. The exact tapering can be obtained by the equation of continuity.

The continuity equation states that in a tube, the following must be true:

$$m^{\cdot}_{\text{in}} = m^{\cdot}_{\text{out}}$$

This equation can be rewritten to:

$$\rho A_1 V_1 = \rho A_2 V_2$$

Or for incompressible flows (where $\rho_1 = \rho_2$):

$$A_1 V_1 = A_2 V_2$$

#### 2.2.3. Runner Area

Runner area should be square cross-section of area as 225 $\text{mm}^2$ as per the gating ratio. In this we have to keep the runner area as constant.

#### 2.2.4. Ingates Design

The ingate can be considered as a weir with no reduction in cross-section of the stream at the gate, then the rate of flow of molten metal to the gates depends on the free height of the metal in the runner and gate area and the velocity with which metal is flowing in the runner. The free height 'h' can be calculated as

$$h = 1.6 \sqrt[3]{\frac{Q2}{gb2}} + \frac{V2}{2g} \text{ mm}$$

### *2.3. Pro-E Modles*

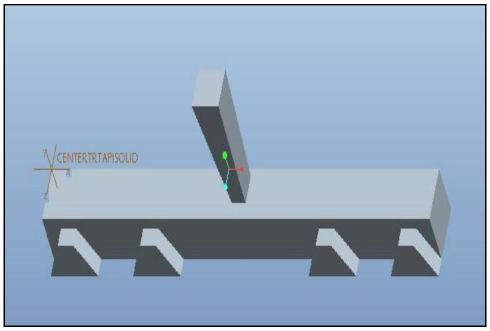


*Figure 2: Centre sprue square cross-section*

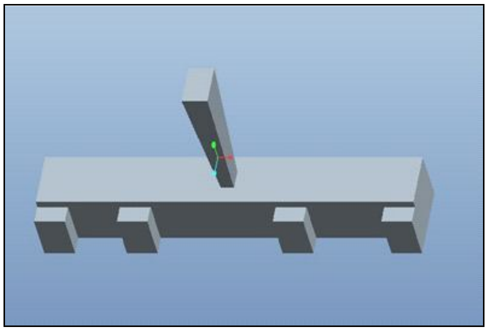


*Figure 3: Centre sprue Trapezoidal cross-section*

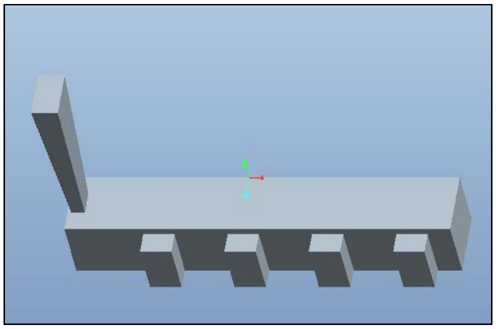


*Figure 4: End sprue square cross-section*

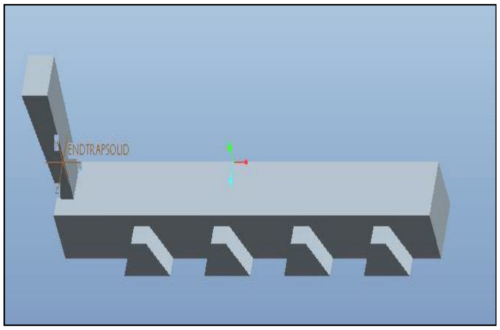


*Figure 5: End sprue Trapezoidal cross-section*

*Figure 6: Experimental set up*

### 3. Procedure

The modular experimental setup for studying the flow of liquid in a multi-gate gating System is shown below. It consists of a pouring basin, a tapered sprue of square cross section, a runner of constant square cross section (15 mm x 15 mm) and four gates of same area of different cross section area as (170 $mm^2$). All these are cut into Perspex blocks and joined for leak-less flow of water. The experimental setup is designed with a gating ratio of 1: 2: 1.5. In the first set of experiments, the sprue is placed at one end, with all four gates to one side, spaced equal-distance from each other. In the second set of experiments, the sprue is placed in the centre, with two gates on either side as shown below. Each set includes nine experiments, with different combinations of gates being open or closed. Water is pumped into the pouring basin to maintain a constant head. The amount of water coming out of each gate is collected into jars and measured. The total time, from start of filling of pouring basin 2 min. is noted. Each individual experiment is repeated thrice and the average values are used for analysis. The observations of the experiments are tabulated for end sprue arrangement and for centresprue arrangement. In the end-sprue arrangement, the time taken to fill a given total volume of liquid depends on the number of open gates and their position, as seen in Table. This can be attributed to the fact that the gates far to the sprue receive metal earlier than other gates, and also have a lesser velocity of flow due to lower low pressure. The difference in filling time is less apparent in centresprue arrangement because of a more balanced flow, The discharge (flow rate) through different gates, when all the gates are open, is observed to be the highest in the gate farthest to sprue and least in the gate closest to the sprue. If one or more gates are closed, then there is obviously more discharge through the open gates, compared to the discharge when all gates are open. In experiments, the discharge through the single open gate is about twice the highest discharge (through the last gate) when all gates are open. In the centresprue arrangement with all gates open (experiment 1), the flow through gates 1 and 4 (farthest from sprue) is about 50% more than the flow through gates 2 and 3 (closest to sprue). The flow is fairly mirrored on both sides of the sprue. When one of the gates nearest to the sprue is closed, then the discharge through the remaining gates increases by 20-25%. Another observation is that the velocity is the highest in the gate nearest to the sprue, and the lowest in the gate farthest from the sprue.

### 4. Experimental Results

#### *4.1. Centre Sprue Rectangular Cross-Section*

In centresprue rectangular cross-section experiment we got the discharge values as in different gates openings are as follows:

| **Discharge Through Each Gate(cm3/sec)** | | | |
|---|---|---|---|
| GATE-1 | GATE-2 | GATE-3 | GATE-4 |
| 27.777 | 5.555 | 5.556 | 28.571 |
| Closed | 31.746 | 6.349 | 29.365 |
| 31.746 | Closed | 5.555 | 30.158 |
| 26.190 | 5.158 | Closed | 35.714 |
| 26.984 | 5.555 | 34.523 | Closed |
| 33.333 | Closed | Closed | 34.126 |
| Closed | 34.523 | 32.936 | Closed |
| Closed | 31.746 | Closed | 35.317 |
| 31.746 | closed | 34.920 | Closed |

*Table 1: discharge through centresprue rectangular cross-section*

#### *4.2. Centre Sprue Trapizodial Cross-Section*

In this experiment we got the discharge values as in different gates openings are as follows:

| **Discharge Through Each Gate($cm^3$/sec)** | | | |
|---|---|---|---|
| GATE-1 | GATE-2 | GATE-3 | GATE-4 |
| 22.619 | 10.714 | 11.111 | 22.222 |
| Closed | 33.750 | 4.583 | 31.250 |
| 25.833 | Closed | 9.583 | 32.916 |
| 21.666 | 11.666 | Closed | 36.666 |
| 21.666 | 12.083 | 36.250 | Closed |
| Closed | 34.166 | 35.833 | Closed |
| 33.750 | Closed | Closed | 35.000 |
| Closed | 33.333 | Closed | 36.250 |
| 33.750 | closed | 35.416 | Closed |

*Table 2: discharge through centresprue trapezoidal cross-section*

### *4.3. End Sprue Rectangular Cross-Section*

In thisend sprue rectangular cross-section experiment we got the discharge values as in different gates openings are as follows:

| **Discharge Through Each Gate(cm3/sec)** | | | |
|---|---|---|---|
| GATE-1 | GATE-2 | GATE-3 | GATE-4 |
| 8.730 | 17.857 | 19.444 | 21.031 |
| closed | 16.666 | 20.000 | 33.333 |
| 10.000 | closed | 22.916 | 37.500 |
| 12.500 | 27.5 | closed | 30.000 |
| 8.750 | 18.333 | 42.083 | Closed |
| closed | 19.583 | 50.000 | Closed |
| 17.916 | closed | closed | 51.666 |
| closed | 23.333 | closed | 45.833 |
| 19.166 | closed | 50.833 | Closed |

*Table 3: discharge through end sprue rectangular cross-section*

### *4.4. End Sprue Trapezoidal Cross-Section*

In end sprue trapezoidal cross-section experiment we got the discharge values as in different gates openings are as follows:

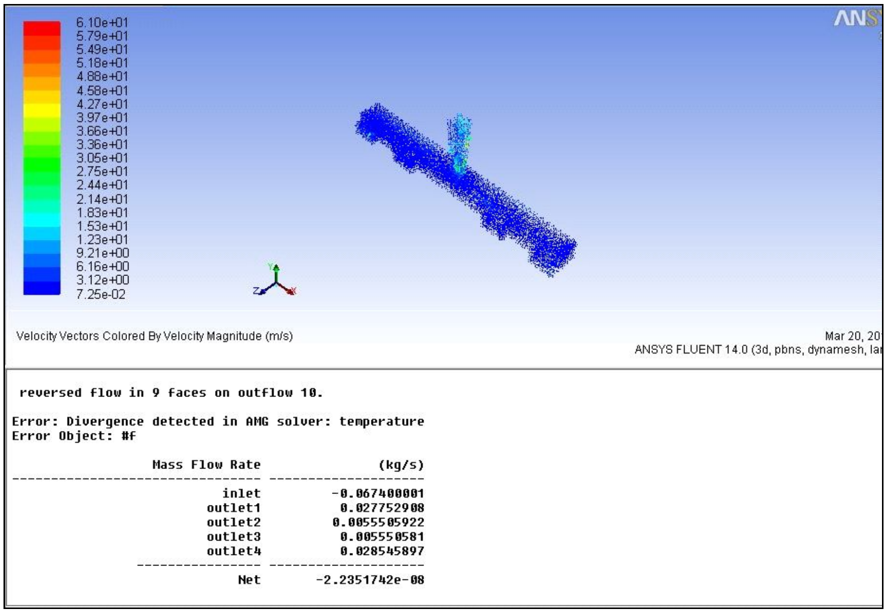
| **Discharge Through Each Gate($cm^3$/sec)** | | | |
|---|---|---|---|
| GATE-1 | GATE-2 | GATE-3 | GATE-4 |
| 7.142 | 7.936 | 23.809 | 28.571 |
| closed | 10.833 | 20.833 | 37.500 |
| 12.916 | closed | closed | 36.666 |
| 10.000 | 24.166 | 20.833 | 36.250 |
| 10.833 | 23.333 | 34.166 | closed |
| closed | 18.750 | 51.250 | closed |
| 31.666 | closed | closed | 37.750 |
| closed | 33.333 | closed | 35.416 |
| 16.666 | closed | 52.083 | closed |

*Table 4: discharge through end sprue trapezoidal cross-section*

## 5. CFD Analysis

### *5.1. Centre Sprue Rectangular Cross-Section*

In centersprue rectangular cross-section arrangement the total inlet is given as 0.06474 kg/s and in all gate opening condition the outlet discharges are as follows.



Velocity Vectors Colored By Velocity Magnitude (m/s)

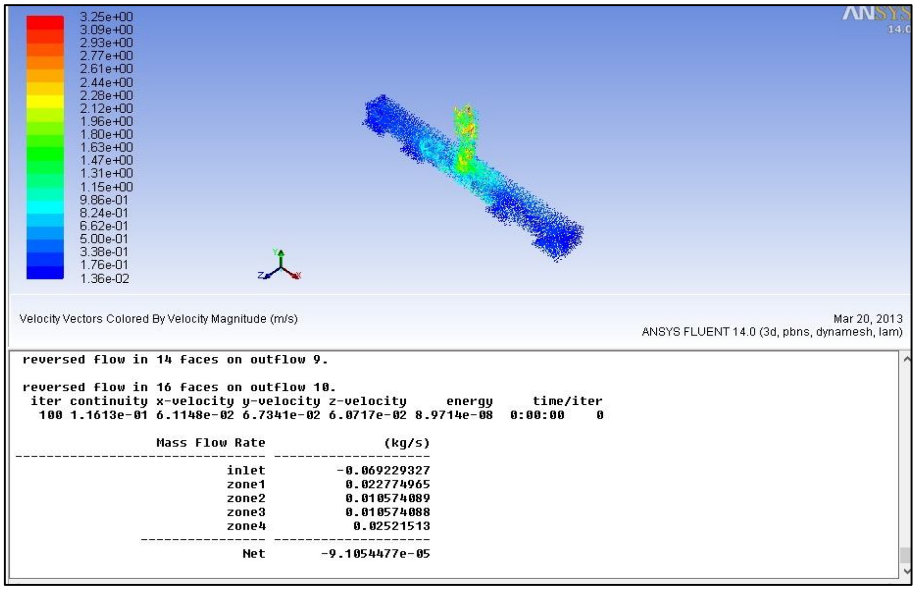
Mar 20, 20
ANSYS FLUENT 14.0 (3d, pbns, dynamesh, la

```
 reversed flow in 9 faces on outflow 10.

Error: Divergence detected in AMG solver: temperature
Error Object: #f

                  Mass Flow Rate                (kg/s)
-------------------------------- --------------------
                           inlet         -0.067400001
                         outlet1          0.027752908
                         outlet2         0.0055505922
                         outlet3          0.005550581
                         outlet4          0.028545897
                ---------------- --------------------
                             Net       -2.2351742e-08
```

Figure 7: discharge through centresprue rectangular cross-section

### *5.2. Centre Sprue Trapezoidal Cross-Section*

In center sprue trapezoidal cross-section arrangement the total inlet is given as 0.066599 kg/s and in all gate opening condition the outlet discharges are as follows.



Velocity Vectors Colored By Velocity Magnitude (m/s)

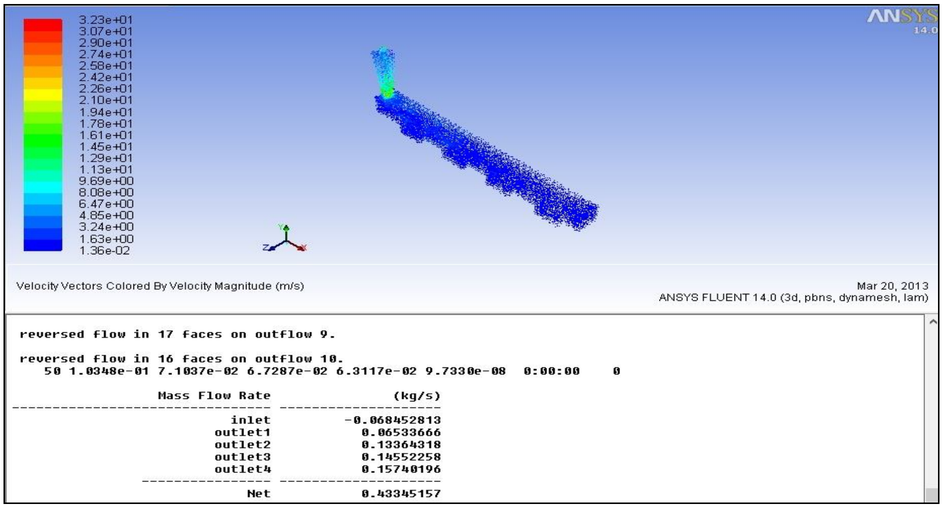
Mar 20, 2013
ANSYS FLUENT 14.0 (3d, pbns, dynamesh, lam)

```
 reversed flow in 14 faces on outflow 9.

 reversed flow in 16 faces on outflow 10.
  iter continuity x-velocity y-velocity z-velocity     energy     time/iter
   100 1.1613e-01 6.1148e-02 6.7341e-02 6.0717e-02 8.9714e-08  0:00:00    0

                  Mass Flow Rate                (kg/s)
-------------------------------- --------------------
                           inlet         -0.069229327
                           zone1          0.022774965
                           zone2          0.010574089
                           zone3          0.010574088
                           zone4           0.02521513
                ---------------- --------------------
                             Net       -9.1054477e-05
```

Figure 8: discharge through centresprue trapezoidal cross-section

### *5.3. End Sprue Rectangular Cross-Section*

In end sprue rectangular crossection arrangement the total inlet is given as 0.06456 kg/s and in all gate opening condition the outlet discharges are as follows.

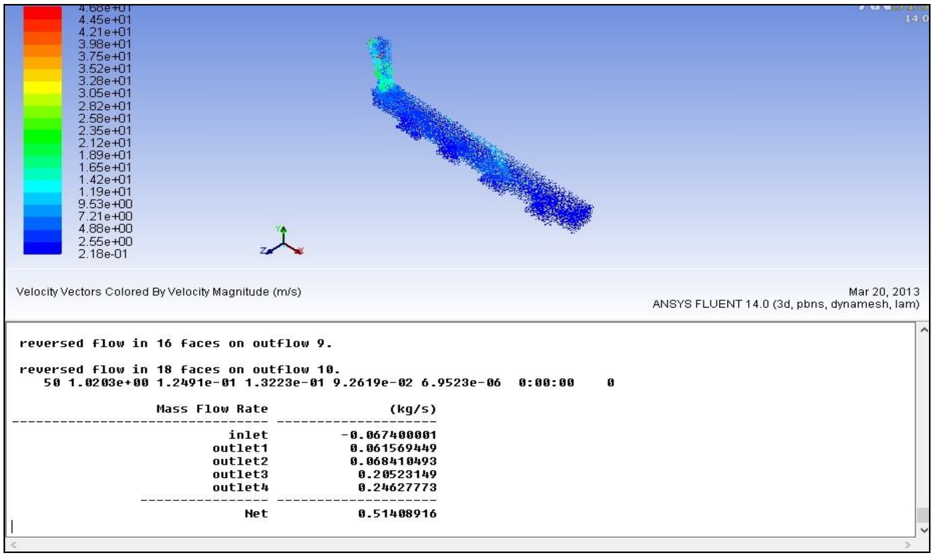


```
reversed flow in 17 faces on outflow 9.

reversed flow in 16 faces on outflow 10.
   50 1.0348e-01 7.1037e-02 6.7287e-02 6.3117e-02 9.7330e-08  0:00:00    0

                  Mass Flow Rate               (kg/s)
-------------------------------- --------------------
                           inlet         -0.068452813
                         outlet1           0.06533666
                         outlet2           0.13364318
                         outlet3           0.14552258
                         outlet4           0.15740196
                ---------------- --------------------
                             Net           0.43345157
```

*Figure 9: discharge through end sprue rectangle cross-section*

*5.4. End Sprue Trapezoidal Cross-Section*

In end sprue trapezoidal crossection arrangement the total inlet is given as 0.06749 kg/s and in all gate opening condition the outlet discharges are as follows.



```
reversed flow in 16 faces on outflow 9.

reversed flow in 18 faces on outflow 10.
   50 1.0203e+00 1.2491e-01 1.3223e-01 9.2619e-02 6.9523e-06  0:00:00    0

                  Mass Flow Rate               (kg/s)
-------------------------------- --------------------
                           inlet         -0.067400001
                         outlet1          0.061569449
                         outlet2          0.068410493
                         outlet3           0.20523149
                         outlet4           0.24627773
                ---------------- --------------------
                             Net           0.51408916
|
```

*Figure 10: discharge through end sprue trapezoidal cross-section*

## 6. Comparitive Study

*6.1. Comparision of Centre Sprue Dischage Results with CFD*

The results obtained from the below table shows that square cross-section is optimized cross-section gives out similar results from all the ingates comparing with other cross-sections.

| DISCHARGE THROUGH EACH GATE(CM$^3$/SEC) | | | | | |
|---|---|---|---|---|---|
| | GATE-1 | GATE-2 | GATE-3 | GATE-4 | |
| experimental | 0.027 | 0.0055 | 0.0055 | 0.0285 | centresprue rectangular cross-section |
| CFD | 0.0277 | 0.0055 | 0.0055 | 0.0205 | |
| experimental | 0.0226 | 0.0107 | 0.0111 | 0.0222 | centresprue trapezoidal cross-section |
| CFD | 0.0223 | 0.0106 | 0.0111 | 0.0223 | |

*Table 5: comparison of discharges of experimental and CFD*

*6.2. Comparision of End Sprue Discharge Resultswith CFD*

The results obtained from the below table shows that rectangle cross-section is optimized cross-section gives out similar results from all the ingates comparing with other cross-sections.

| DISCHARGE THROUGH EACH GATE(CM$^3$/SEC) | | | | | |
|---|---|---|---|---|---|
| | GATE-1 | GATE-2 | GATE-3 | GATE-4 | |
| experimental | 0.0080 | 0.0718 | 0.0194 | 0.0210 | end sprue rectangular cross-section |
| CFD | 0.0653 | 0.1336 | 0.1455 | 0.1575 | |
| experimental | 0.0071 | 0.0079 | 0.0238 | 0.0280 | end sprue trapezoidal cross-section |
| CFD | 0.00615 | 0.0685 | 0.02852 | 0.0242 | |

*Table 6: comparison of discharges of experimental and CFD*

## 7. Graph Results

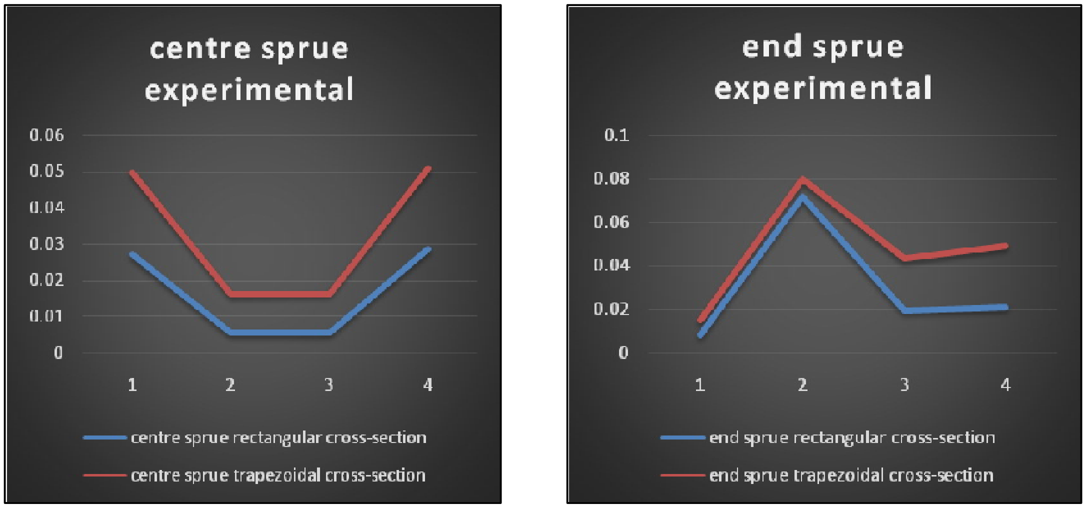


*Figure 11: Discharges through various cross section for CENTRE and END sprues.*

## 8. Conclusion

- From Experimental and simulation results, we can conclude that the Centre Sprue result is better than End Sprue results.
- The discharge (flow rate) through different gates, when all the gates are open, is observed to be the highest in the gate farthest to sprue and least in the gate closest to the sprue.
- In Centre Sprue Arrangement Square Cross-Section gives Optimized Results, due to equal distribution of the fluid velocity. Discharge (kg/sec) through each gate is 0.0214, 0.0119, 0.0115, and 0.0218 respectively.
- In Centre Sprue Arrangement Square Cross-Section gives Optimized Results, due to equal distribution of the fluid velocity. Discharge (kg/sec) through each gate is 0.0075, 0.0134, 0.0218 and 0.0246 respectively.
- From these results we have found that Centre Sprue Square Cross-section is optimized cross-section for filling the mould cavity.

## 9. References

1. K.H. Renukananda, AkashChavan and Dr. B. Ravi “Flow Rates in Multi-Gate Systems:Experimental and Simulation Studies” Indian Foundry Journal, Vol.58, No.4, April 2012.
2. M. R. Barkhudarov “Advanced Simulation of the Flow and Heat Transfer Processes in Simultaneous Engineering” Flow Science, Inc., 1257 40-th Street, Los Alamos, New Mexico 87544, USA
3. Dr. B. Ravi “Casting Design Optimization driven by Simulation” Metal Casting: Computer-Aided Design and Analysis, PHI India, New Delhi, 2005-2008, ISBN 81 203 2726 8.
4. S. Guleyupoglu, “Casting Process Design Guidelines”.
5. Layton, and W.Sahin, “A problem solving approach using les for a back word facing step”2002.
6. M.M.Atha vale and H.Q. Yang coupled field thermal structural simulation in micro channels.
7. Zhizhong SUN, Henry HUy, Xiang CHEN, Qigui WANG and Wenying YANG, “Gating System Design for a Magnesium Alloy Casting”, J. Mater. Sci. Technol., Vol.24 No.1, 2008.
8. Kazuhiro Nakahashi, “Navier –stokes computations of two and three dimensional cascade floefields”, Vol.5,no.3, May – june 1989.
9. PETI Ferencz, GRAMA Lucian, SOLOVĂSTRU Ioan, CORBA Cristian, “Studies Concerning The Design Of The Runner, Gate And Venting Systems In The Case Of The High Pressure Die Casting Technology” ANNALS of the ORADEA UNIVERSITY. Fascicle of Management and Technological Engineering, Volume IX (XIX), 2010, NR2
10. Y. Wang, K. Kabiri-Bamoradian and R.A. Miller, “Runner design optimization based on CFD simulation for a die with multiple cavities”
11. Feng Liu, “ Optimized Design of Gating/Riser System in Casting Based on CAD and Simulation Technology”