COMPUTER AIDED ANALYSIS AND DESIGN OF RISERS

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تحليل وتصميم المغذيات باستخدام الحاسب الآلى

ملخص : يعتبر اختيار المغذى المناسب من أهم العوامل التى تؤثر على جودة المسبوك . وقد اعتمد تصميم المغذى دائما على معادلات معملية خاصة فى الحالات المعقدة (استخدام المبردات أو المواد العازلة) . وتحتوى هذه المعادلات المعملية عادة على كم كبير من المعاملات التى يتم اختيارها من قبل المصمم . ونظرا لأن لهذه العوامل مجالا كبيرا للتغيير حتى تناسب كافة أشكال المسبوكات ؛ فقد أصبحت نتيجة تصميم المغذى تختلف اختلافا كبيرا تبعا لخبرة المصمم . وقد أدى هذا الى صعوبة وضع نظام متكامل لتصميم المغذيات باستخدام الكمبيوتر ؛ حيث أن من أهم أهداف أى نظام هو الوصول الى نفس النتائج لنفس الحالة مع أى مستخدم بصرف النظر عن خبرته.

وقد قمنا فى هذا البحث بتحليل رياضى للمغذيات – خاصة المغذيات المعزولة من الجانب – لايجاد حل مضبوط لها . وقد تم ايجاد هذا الحل عن طريق الحساب المضبوط للوقت الازم لتجمد كل من المسبوك والمغذى. و تم تطوير نظام لتصميم المغذى فى جميع الحالات المستخدمة وهى : المغذيات المفتوحة , والمغذيات المدفونة . وفى حالة استخدام المبردات أو المواد العازلة أو كليهما. ويتميز البرنامج المطور بسهولة الاستخدام وبالنتائج الدقيقة دون الاعتماد على خبرة المصمم .

ABSTRACT

A sound Casting depends on the best selection and design of risers and gating system. One of the most important goals of computerizing is to have the same results for the same situation with each user in spite of his experience. Using empirical rules can not achieve that, because there are a lot of coefficients in any equation that must be chosen, they have a wide range to suit different problems. The objective of this work is to present a mathematical analysis of risers, especially side insulated risers. Formulas will be driven theoretically for calculating the riser volume, depending on exact calculation of solidification time of both casting and riser. An exact and best solution have been made for this problem which was always treated by empirical formulas. Two case studies have been made with great satisfaction.

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1 INTRODUCTION

Of all the engineering phases involved in manufacturing a quality casting, the least appreciated and most important is the mechanism by which metal freezes. The techniques for melting and handling the metal and preparing the mold are fairly well understood, and are subject to constant, positive control in any good shop. All too often, however, as soon as the metal fills the mold, control ends, and solidification proceeds according to the whims of nature; and element of mystery enters the metal casting process. Solidification of metals was, indeed, a mystery, which has an important relation with the riser and gating system design.

Risers are added reservoirs designed to feed liquid metal to the solidifying casting as a means of compensating for solidifying shrinkage [1]. To perform this function, the risers must solidify after the casting. In this way, the riser can continuously feed molten metal and will compensate for the solidification shrinkage of the entire mold cavity. This leads the designer to the fact, that, risers should be designed to conserve metal, which is the main objective behind this work.

The use of computer aided design techniques in casting processes had begun since 1960s. One of these processes is the riser design. Some researches concentrated on riser volume calculation using known empirical rules [2,3,4]. Most of these work concerned only the design of simple risers (i.e. risers without chills or insulators).Others, worked on determining the best location of riser [5].

One of the most important goals of computerizing is to have the same results for the same situation with each user in spite of his experience. Using empirical rules can not achieve that because there are a lot of coefficients in any equation that must be chosen by the user. The coefficients have a wide range to suite different problems. Different choices will lead certainly to very different results. In this work formulas will be driven theoretically for calculating the riser volume, depending on exact calculation of solidification time of both the casting and the riser. A computer software called "CASTING" , which has been recently described [6] , was developed to computerize the process of pattern and mold design. This software consists of eight modules. One of these modules is the riser design module which is described in details in this paper.

2 THERMAL ANALYSIS OF RISERS

The earliest known quantitative risering analysis is that of Chvorinov [7]. Chovorinov showed that :

$$t = k\left(\frac{V}{A}\right)^2 \tag{1}$$

Where *t = Freezing time* *V = Casting volume,* *A = Surface area of casting*
K = Constant that depends mainly on mold and casting material.

Attempts have been made to calculate riser (using Chvorinov's rule) by considering the riser and casting as two separate casting, and determine a riser size such that :

$$\left(\frac{V}{A}\right)_{riser} > \left(\frac{V}{A}\right)_{casting}$$

Such attempts have not been successful, however, because Chvorinov's rule takes no account of solidification shrinkage. Adams and Taylor have developed a rule for designing simple risers (blind risers with no chills or insulating material) based on thermal analysis of the mold [7,8]. The rule is as follows :

$$\frac{V_{Rf}}{A_R} = \frac{V_C}{A_C} \quad (2)$$

$$V_{Rf} = \frac{\pi}{4} D_r^3 * U \quad (3)$$

$$V_R = V_{Rf} + f(V_R + V_C) \quad (4)$$

This equation depends on the fact that the riser may be considered as a simple casting. For more complicated risers it is necessary to calculate the solidification time for both riser and casting.

2-1 Solidification Time For Casting

The amount of heat in the casting is divided into two quantities; the super heat and the latent heat. The casting solidification time is given by the following formula; [8] :

$$C_{st} = \frac{\pi C_{pm}^2 \rho_m^2 V^2 (T_p - Tm)^2}{4 A^2 k \rho C_p (T_{pm} - T_i)^2} + \frac{\pi H_f^2 \rho_m^2 V^2}{4 A^2 k \rho C_p (T_m - T_i)^2} \quad (5)$$

The first term in the right hand side of equation "5" stands for the time required for the metal to lose its superheat, whereas the second term stands for the time required for changing the phase of the metal from liquid to solid.

2-2 Solidification Time for Casting with Chills

The heat absorbed by the chill depends on its heat capacity, thermal conductivity, density and volume.

$$Q_{ch} = C_{chill} K_{chill} \rho_{chill} V_{chill} \quad (6)$$

Note : The thermal conductivity of the chill material is considered to be >> that of the *casting sand (Thermal conductivity of the silica sand equals to about 0.5 w/m.k whereas that of the steel varies between 46 and 56 w/m.k) so we can neglect the heat transferred through the mold before the chill saturation.*

Four cases for the chill are as following :

1- $Q_{ch} < Q_{sh}$

$$t_{ch} = \frac{\pi \, Q_{ch}^2}{4 \, A_{cc}^2 \; K_{ch} \, \rho_{ch} C_{ch} \, (T_{pm} - T_i)^2} \tag{7}$$

$$t_{sh} = \frac{\pi \, (Q_{sh} - Q_{ch})^2}{4 \, A^2 \; K \rho \, C \, (T_{pm} - T_i)^2} \tag{8}$$

$$t_s = \frac{\pi \, Q_s}{4 \, A^2 \, k \, \rho \, C_p \, (T_m - T_i)^2} \tag{9}$$

$$C_{st} = t_s + t_{sh} + t_{ch} \tag{10}$$

2- $Q_{ch} = Q_{sh}$

$$t_{ch} = \frac{\pi \, Q_{ch}^2}{4 \, A_{cc}^2 \; K_{ch} \, \rho_{ch} \, C_{ch} \, (T_{pm} - T_i)^2} \tag{11}$$

$$t_s = \frac{\pi \, Q_s}{4 \, A^2 \, k \, \rho \, C_p \, (T_m - T_i)^2} \tag{12}$$

$$C_{st} = t_{ch} + t_s \tag{13}$$

3 - $Qsh < Qch < (Qsh + Qs)$

$$t_{ch1} = \frac{\pi \, Q_{sh}^2}{4 \, A_{cc}^2 \; K_{ch} \, \rho_{ch} \, C_{ch} \, (T_{pm} - T_i)^2} \tag{14}$$

$$t_{ch2} = \frac{\pi \, (Q_{ch} - Q_{sh})^2}{4 \, A_{cc}^2 \; K_{ch} \, \rho_{ch} \, C_{ch} \, (T_{pm} - T_i)^2} \tag{15}$$

$$t_s = \frac{\pi \, (Q_s + Q_{sh} - Q_{ch})^2}{4 \, A^2 \, k \, \rho \, C_p \, (T_m - T_i)^2} \tag{16}$$

$$C_{st} = t_{ch1} + t_{ch2} + t_{sh} \tag{17}$$

4 - $Qch \geq (Qsh + Qs)$

$$t_{ch1} = \frac{\pi \, Q_{sh}^2}{4 \, A_{cc}^2 \; K_{ch} \, \rho_{ch} \, C_{ch} \, (T_{pm} - T_i)^2} \tag{18}$$

$$t_{ch2} = \frac{\pi \; Q_s^2}{4 A_{cc}^2 \; K_{ch} \rho_{ch} C_{ch} \; (T_m - T_i)^2} \tag{19}$$

$$C_{st} = t_{ch1} + t_{ch2} \tag{20}$$

2-3 Solidification Time for Open Riser

In blind riser the heat is transferred only through conduction to the mold where in open riser the heat is transferred through conduction to the mold and through convection and radiation to the air.

$$R_{st} = t_{rs} + t_{rsh} \tag{21}$$

The superheat transferred from the riser (Q_{sh}) equals to :

$$Q_{sh} = Cpm * \rho_m * V_R * (Tp - Tm) \tag{22}$$

The heat transferred from the riser during time " t " is equal to

$$Q = Q_c + Q_{con} + Q_r \tag{23}$$

$$Q_c = \frac{2A_{side}}{\sqrt{\pi}} \sqrt{k \rho C_p} \; (T_{pm} - T_i) \; t^{0.5} \tag{24}$$

$$Q_{con} = A_{top} h \, (T_{pm} - T_i) \, t \tag{25}$$

$$Q_r = A_{top} \, \varepsilon \sigma (T_{pm}^4 - T_i^4) \, t \tag{26}$$

Setting equations (22) & (23) equal we get :

$$C_{pm} * \rho_m * V_R * (T_p - T_m) = \frac{2A_{side}}{\sqrt{\pi}} \sqrt{k \rho C_p} \; (T_{pm} - T_i) \; t_{rsh}^{0.5} + A_{top} h \, (T_{pm} - T_i) \, t_{rsh} + A_{top} \, \varepsilon \sigma (T_{pm}^4 - T_i^4) \, t_{rsh} \tag{27}$$

The solidification heat transferred from the riser equals to (Q_s).

$$Q_s = H_f * \rho_m * V_{rf} \tag{28}$$

Setting equations (23) & (28) equal we get :

$$H_f * \rho_m * V_R = \frac{2A_{side}}{\sqrt{\pi}} \sqrt{k \rho C_p} \; (T_{pm} - T_i) \; t_{rs}^{0.5} + A_{top} h \, (T_{pm} - T_i) \, t_{rs} + A_{top} \, \varepsilon \sigma (T_{pm}^4 - T_i^4) \, t_{rs} \tag{29}$$

Solving both equations (27) & (29) numerically yields the values of t_{rs} & t_{rsh}.

2-4 Top Insulated Risers

It will be assumed that the insulation is a perfect one. So the beat transferred by convection and radiation is neglected and the right hand side in equations (27) and (29) will be reduced to its first part only.

2-5 Side Insulated Riser

Heat conduction through composite media arises frequently in engineering applications; the problem of side **insulated riser** is a good example. There are practical formulas to deal with this problem.

I- Theoretical Formulation

The system may be reduced into a two layer cylinder as illustrated in Fig.1. The system contains an inner region $\mathbf{R_1} \le \mathbf{r} \le \mathbf{R_2}$ and an outer region $\mathbf{R_2} \le \mathbf{r} \le \mathbf{R_3}$. **K1** and **K2** are the thermal conductivities , $\alpha 1$ and $\alpha 2$ are the thermal diffusivities of the inner and outer regions, respectively.

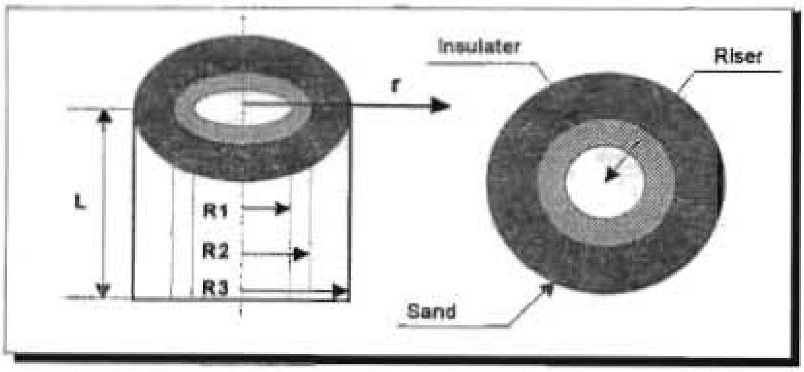

Fig. 1 Representation of a Side Insulated Riser

Two conditions are assumed :

i. The two regions are in perfect thermal contact (i.e. there no thermal resistance between them).

ii. The mold is considered semi-infinite in extent

□II- Governing equation and boundary conditions

The governing equation in the i_{th} layer of this composite may be written as :

$$\alpha_i \left[\frac{\partial^2 T_i(r,t)}{\partial r^2} + \frac{1}{r} \frac{\partial T_i(r,t)}{\partial r} \right] = \frac{\partial T_i(r,t)}{\partial t} \qquad (30)$$

Where ;

$$\alpha_i = \frac{K_i}{\rho_i \, Cp_i} \; , i = 1,2$$

and $T_i\ (r,t)$ = The temperature in region (i), at a distance (r) from the composite center, at time (t).

Subject to the following boundary conditions :

• The metal temperature being constant through the solidification time and equal to the melting temperature - denoted by g_o - implies that :

$$T_1(r,t) = g_o \qquad \text{at } r = R_1, \qquad t > 0 \qquad \text{(31 a)}$$

• The continuity of temperature or perfect thermal contact at the interface between the two layers implies that :

$$T_1(r,t) = T_2(r,t) \qquad \text{at } r = R_2, \qquad t > 0 \qquad \text{(31 b)}$$

• Since the system is considered semi-infinite (i.e. R3 is very large) :

$$T_2(r,t) = T_o \qquad \text{at } r = R_3, \qquad t > 0 \qquad \text{(31 c)}$$

• The heat flux being continuous at the interface implies that :

$$K_1 \frac{\partial T_1(r,t)}{\partial r} = K_2 \frac{\partial T_2(r,t)}{\partial r} \qquad \text{at } r = R_2 \qquad t > 0 \qquad \text{(31 d)}$$

and the initial condition :

$$\bullet\ T_i(r,t) = T_o \qquad 0 < r < R_3 \qquad \text{(31 e)}$$

The temperature distribution in each region is obtained by simultaneously solving the above system of partial differential equations subject to the displayed conditions. The exact solution of the system of differential equation given by equation (30), subject to boundary conditions (31) is obtained by employing the **finite integral transform technique** [9]. which yields that :

$$T_i(r,t) = \sum_{n=1}^{\infty} \frac{\psi_{i,n}(r)}{N(\lambda_n)} \left[(\phi_n(0) + \frac{L}{\lambda_n^2})\, e^{-\lambda_n^2 t} - \frac{L}{\lambda_n^2} \right] \qquad (32)$$

Where :

$$\psi_{i,n}(r) = A_{i,n} J_o\left(\frac{\lambda_n}{\sqrt{\alpha_i}} r\right) + B_{i,n} Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_i}} r\right) \qquad (33)$$

$J_o\left(\frac{\lambda_n}{\sqrt{\alpha_i}} r\right)$ and $Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_i}} r\right)$ are the Bessel functions of order zero of the first and second kind respectively.

$$
\begin{aligned}
N(\lambda n) = {} & \frac{K_1 R_2^2}{2\alpha_1}\left[J_o^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right) + J_1^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right)\right] - \\
& \frac{K_1 R_1^2}{2\alpha_1}\left[J_o^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right) + J_1^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right)\right] + \\
& \frac{K_1 R_2^2 B_{1,n}}{2\alpha_1}\left[J_o\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right) Y_o\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right) + J_1\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right) Y_1\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right)\right] - \\
& \frac{K_1 R_1^2 B_{1,n}}{2\alpha_1}\left[J_o\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right) Y_o\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right) + J_1\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right) Y_1\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right)\right] + \\
& \frac{K_1 R_2^2 B_{1,n}^2}{2\alpha_1}\left[Y_o^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right) + Y_1^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_2\right)\right] - \\
& \frac{K_1 R_1^2 B_{1,n}^2}{2\alpha_1}\left[Y_o^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right) + Y_1^2\left(\frac{\lambda n}{\sqrt{\alpha_1}} R_1\right)\right] + \\
& \frac{K_2 R_3^2 A_{2,n}^2}{2\alpha_2}\left[J_o^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right) + J_1^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right)\right] - \\
& \frac{K_2 R_2^2 A_{2,n}^2}{2\alpha_2}\left[J_o^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right) + J_1^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right)\right] + \\
& \frac{K_2 R_3^2 A_{2,n} B_{2,n}}{2\alpha_2}\left[J_o\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right) Y_o\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right) + J_1\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right) Y_1\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right)\right] - \\
& \frac{K_2 R_2^2 A_{2,n} B_{2,n}}{2\alpha_2}\left[J_o\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right) Y_o\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right) + J_1\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right) Y_1\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right)\right] + \\
& \frac{K_2 R_3^2 B_{2,n}^2}{2\alpha_2}\left[Y_o^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right) + Y_1^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_3\right)\right] - \\
& \frac{K_2 R_2^2 B_{2,n}^2}{2\alpha_2}\left[Y_o^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right) + Y_1^2\left(\frac{\lambda n}{\sqrt{\alpha_2}} R_2\right)\right]
\end{aligned}
\tag{34}
$$

$$
B_{1,n} = \frac{1}{\Delta}\left[J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_1\right) \frac{K_2\lambda_n}{\sqrt{\alpha_2}} \left(\frac{-2\sqrt{\alpha_2}}{\pi\lambda_n R_2}\right)\right] \tag{35}
$$

$$A_{2,n} = \frac{1}{\Delta}\Bigg[-Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_1\right)\Bigg(\frac{K_2\lambda_n}{\sqrt{\alpha_2}}J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_1\right)$$

$$-\frac{K_1\lambda_n}{\sqrt{\alpha_1}}Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)J_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)\Bigg)$$

$$-J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)\Bigg(\frac{K_2\lambda_n}{\sqrt{\alpha_2}}Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)$$

$$-\frac{K_1\lambda_n}{\sqrt{\alpha_1}}Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)\Bigg)\Bigg]$$

(36)

$$B_{2,n} = \frac{1}{\Delta}\Bigg[-Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_1\right)\Bigg(\frac{K_1\lambda_n}{\sqrt{\alpha_1}}J_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)J_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)$$

$$-\frac{K_2\lambda_n}{\sqrt{\alpha_2}}J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)J_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)\Bigg)$$

$$+J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_1\right)\Bigg(-\frac{K_2\lambda_n}{\sqrt{\alpha_2}}Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)J_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)$$

$$+\frac{K_1\lambda_n}{\sqrt{\alpha_1}}J_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)\Bigg)\Bigg]$$

(37)

Where :

$$\Delta = -Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_1\right)\left(\frac{K_2\lambda_n}{\sqrt{\alpha_2}}\right)\left(\frac{-2\sqrt{\alpha_2}}{\pi\lambda_n R_2}\right) \tag{38}$$

$$\phi_n(0) = \frac{K_1}{\alpha_1}\frac{\sqrt{\alpha_1}}{\lambda_n}\Bigg[R_2 J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right) + B_{1,n}R_2Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_2\right)$$

$$-R_1 J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_1\right) + B_{1,n}R_1Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}}R_1\right)\Bigg]$$

$$+\frac{K_2}{\alpha_2}\frac{\sqrt{\alpha_2}}{\lambda_n}\Bigg[A_{2,n}R_3J_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_3\right) + B_{2,n}R_3Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_3\right)$$

$$-A_{2,n}R_2J_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right) + B_{2,n}R_2Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}}R_2\right)\Bigg]$$

(39)

$$L = K_2 R_3 \left[A_{2,n} J_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_3\right) + B_{2,n} Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_3\right) \right] T_o$$

$$K_1 R_1 \frac{\lambda_n}{\sqrt{\alpha_1}} \left[J_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_1\right) + B_{1,n} Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_1\right) \right] g_o \qquad (40)$$

λ_n is given by the following equtiaon

$$\begin{vmatrix} J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_1\right) & Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_1\right) & 0 & 0 \\ J_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_2\right) & Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_2\right) & -J_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_2\right) & -Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_2\right) \\ \frac{K_1\lambda_n}{\sqrt{\alpha_1}} J_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_2\right) & \frac{K_1\lambda_n}{\sqrt{\alpha_1}} Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_1}} R_2\right) & \frac{K_2\lambda_n}{\sqrt{\alpha_2}} J_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_2\right) & -\frac{K_2\lambda_n}{\sqrt{\alpha_2}} Y_1\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_2\right) \\ 0 & 0 & -J_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_3\right) & -Y_o\left(\frac{\lambda_n}{\sqrt{\alpha_2}} R_3\right) \end{vmatrix} = 0 \qquad (41)$$

$$Q_c = K_1 A_{side} \left. \frac{\partial T(r,t)}{\partial r} \right|_{r=R_1} \qquad (42)$$

Then equation (27) & (29) will be in the form :

$$C_{pm} * \rho_m * V_R * (T_p - T_m) = K_1 A_{side} \left. \frac{\partial T(r,t)}{\partial r} \right|_{r=R_1} + A_{top} h (T_{pm} - T_i) t_{rsh} + A_{top} \varepsilon \sigma (T_{pm}^4 - T_i^4) t_{rsh} \qquad (43)$$

$$H_f * \rho_m * V_R = K_1 A_{side} \left. \frac{\partial T(r,t)}{\partial r} \right|_{r=R_1} + A_{top} h (T_{pm} - T_i) t_{rs} + A_{top} \varepsilon \sigma (T_{pm}^4 - T_i^4) t_{rs} \qquad (44)$$

Notes :

1- For top insulated risers only the first term in the right hand side of equations **(43)**& **(44)** is exist.

2- For blind risers equations **(43)** & **(44)** are applied but **Aside** is replaced by **Aside + Atop**

3 RISER DESIGN MODULE

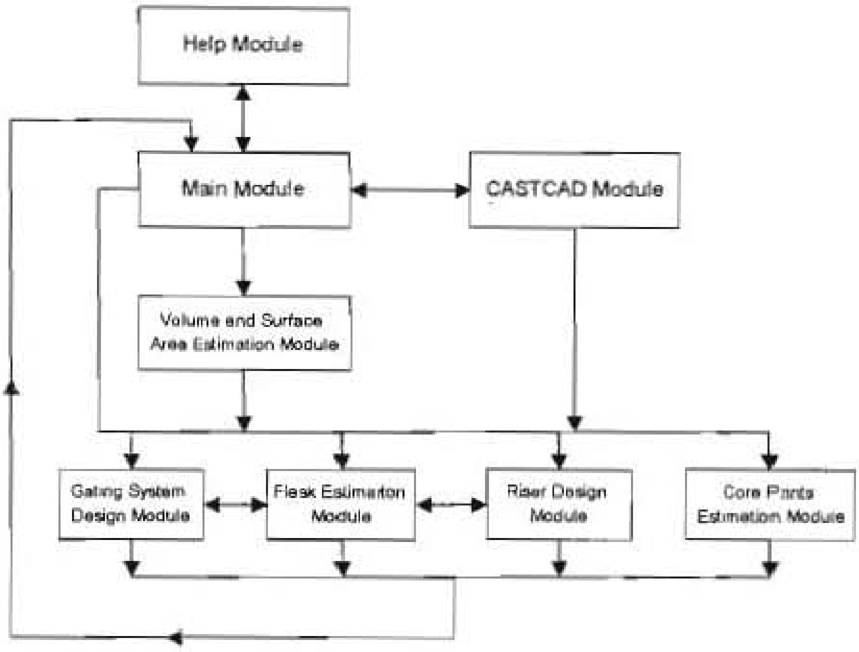

Fig. 2 System modules

Figure 2 shows the developed software which consists of eight modules. The Riser Design Module needs information from the CASTCAD module -or the Volume and Surface Area Design Module- such as the casting volume and surface area. It also needs the flask dimensions which is calculated through the Flask Estimation Module. The cores total area is calculated by the Core Prints Estimation Module. The Help Module offers the required help for the user [6]. The program is written in Basic "Visual Basic version 3 professional edition was used ", therefore, it must be run under "Windows". To run the program with its facilities, the computer must be -at least- 386 SX, with 4MB ram, a hard disk loaded with Windows and AutoCAD V. 12 software, a mouse and a coprocessor.

The Riser Design Module contains a large variety of riser situations. It can deal with cases of open risers, blind risers, top insulated risers, side insulated risers, risers for chilled castings, and any combination of these cases. Figure 3 shows the flowchart of this module. The procedure is as follows:

1- Simple riser. If the riser is simple (blind riser , with no chills, and no insulator) then its volume (V_R)will be calculated directly from equations **(2)** to **(4)**.

2- Casting solidification time. The program calculates the casting solidification time using equation (5) for non chilled castings, and equations (7) **to (20)** for chilled castings.

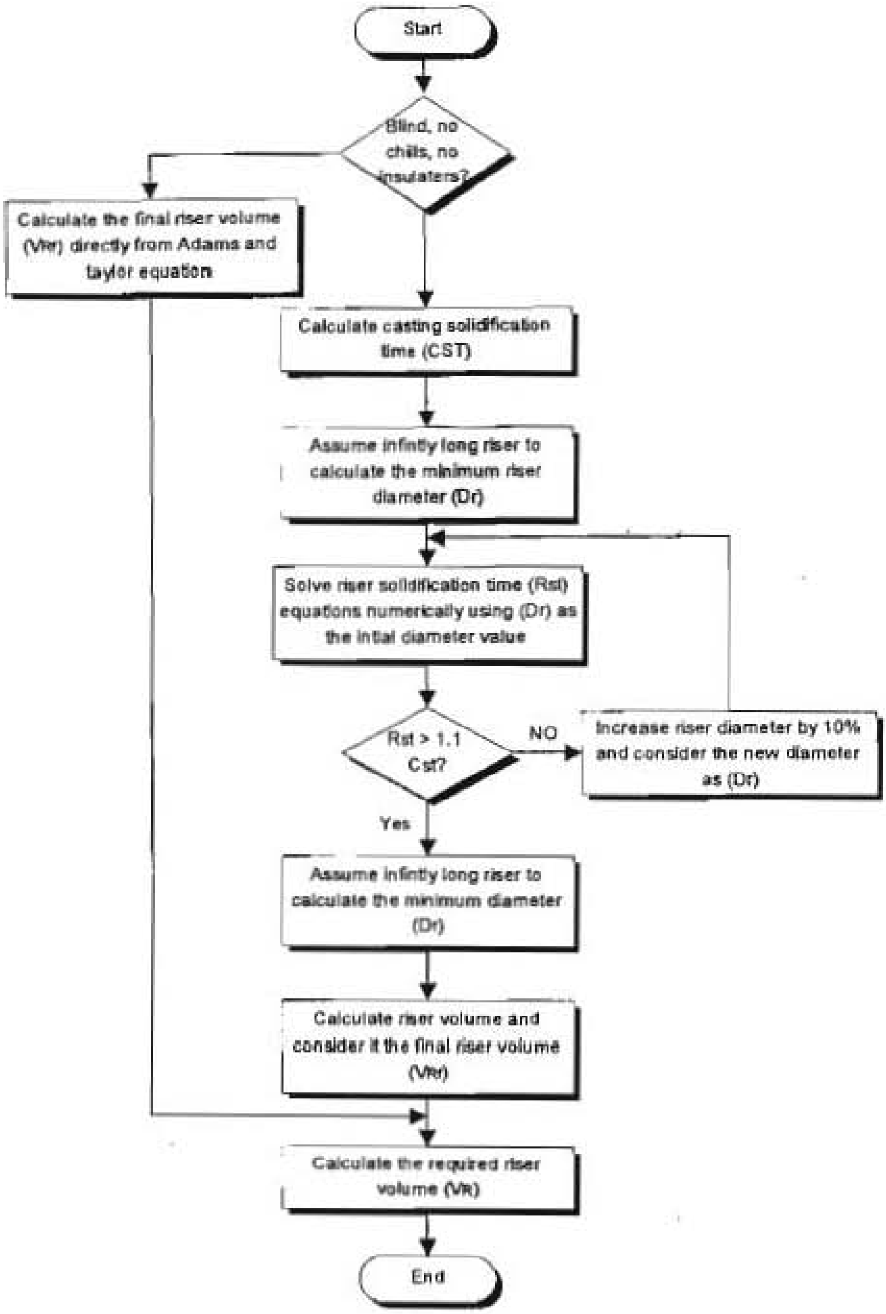

Fig.3 Riser design module flowchart

3- **Riser solidification time.** Riser solidification equations are solved numerically using Newton Raphson method. It is assumed that the riser is infinitely long, so one can get the minimum riser diameter and use it as the initial value for riser diameter (D_r).

4- **Riser volume.** If the riser solidification time $(R_{st}) \geq 1.1(C_{st})$ then the final riser volume (V_{Rf}) is calculated from equation (3). If not the riser diameter is increased by 10% and calculations are repeated again.

3-1 Editing Riser Conditions

Choosing **Riser** command from the **Edit** menu will open the riser editing screen, Fig. 4. This screen contains :

1- **Length to diameter ratio.** This is the ratio between the height of the metal in the riser and its diameter. The default value is 1, but the user can change it according to his experience. To change this ratio, the new value is written in the text box instead of the old one.

2- **Open or Blind Riser.** There are two radio buttons to choose one from them. The first one - which is the default one - means that the riser is open, whereas the second means that the riser is blind. The user can change this choice by clicking the required choice by the mouse pointer.

3- **Top insulation.** To add top insulation the user marks the shown check box. The default choice is no top insulation (i.e. the check box is unmarked).

4- **Adding chills.** To add chills the user presses the **Chills** button and the view changes to Fig. 5 . The new view contains a frame to define the chill characteristics. There are two radio buttons to choose between external chill and internal chills. Internal chills will be from the same material as the casting. Choosing external chills radio button will give a list of materials to choose from them. Also the user writes the chill volume and its contact surface with the casting in the text boxes.

• **Adding side insulation.** To add side insulation the user presses the **Side Insulation** button and the view changes to Fig. 6 . The new view contains a frame to define the chill characteristics. There are 4 radio buttons to choose the insulation material. Three materials are defined to the program. If the user is to use another material, he has to enter its thermal conductivity in the shown text box. Also the program needs the insulation thickness.

4 CONCLUSIONS

An extensive work have been done on the thermal analysis of risers. The problem of insulated riser solidification was modeled as a heat conduction problem and the exact solution was reached. The developed solution will be used instead of the empirical formulas which need a lot of experience to estimate its variables.

A comprehensive foundry CAD system has been developed to assist the casting engineer in the design of a riser for ferrous and non-ferrous metals providing low cost, fast and accurate method. Most of sophisticated geometrical shapes can be treated through this program. The system has the flexibility to change one or more of the casting process

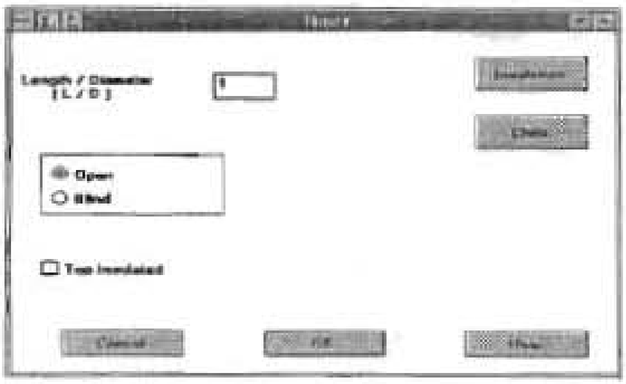

Fig.4 Riser Editing Screen

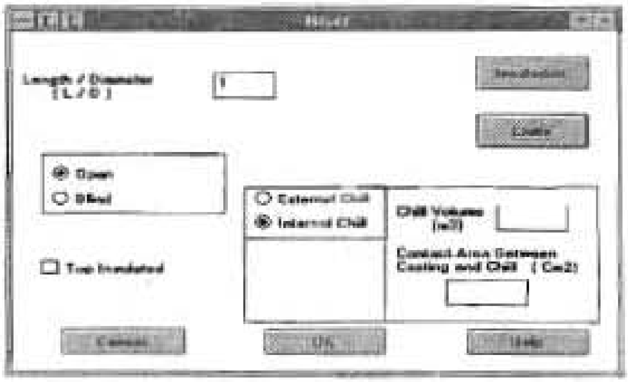

Fig.5 Riser Editing Screen with chills

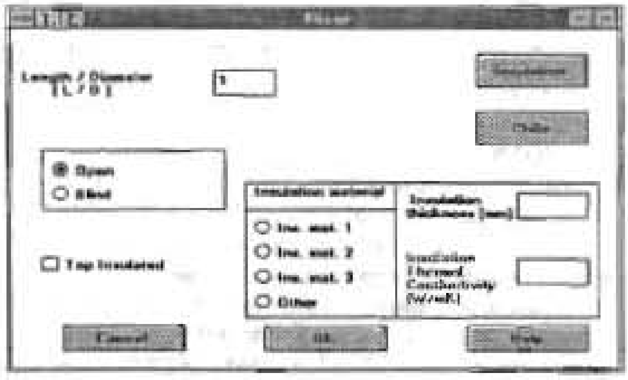

Fig.6 Riser Editing Screen with insulators

variables (i.e. adding chills, changing gating position etc.) and makes it very easy for the designer in case of modifying / changing or using a new alternative. the system operated by the users regardless their skills and experiences and retrieve data and AutoCAD drawings.

NOMENCLATURE

V_{Rf} = final Riser volume (after complete solidification) (m^3).
V_C = Casting Volume (m^3).
A_R = Riser surface area (m^2).
A_C = Casting surface area (m^2).
V_R = The initial volume of the riser (m^3).
f = Solidification shrinkage .
D_r = Riser diameter (m).
U = Length to diameter ratio.
C_{st} = Total solidification time for the casting (sec).
Cpm = Heat capacity of the casted metal (J/ kg K).
ρ_m = Density of the casted metal (kg / m^3).
V_c = Casting volume (m^3).
Tp = Pouring temperature (K).
T_m = melting temperature (K).
H_f = Latent heat (J / kg).
A = Surface area of the casting (m^2)
k = The effective thermal conductivity of the mold material (W/ m K).
(Note : The effective thermal conductivity includes the heat conduction by convection and radiation in the mold material particles).
ρ = Mold material density (kg / m^3).
C_p = Heat capacity of the casting sand (J / kg K).
Tpm = Mean temperature between the pouring temperature and melting temperature.
$Tpm = 0.5\,(Tp + T_m)$ (K)
T_s = Temperature of the surroundings (K).
C_{chill} = Heat capacity of the chill material (J/ kg K).
K_{chill} = Thermal conductivity of the chill material (W/ m K).
ρ_{chill} = Density of the chill material (kg / m^3).
V_{chill} = Volume of the chill (m^3).
Qch = The heat absorbed by the chill (W).
A_{cc} = The contact area between the chill and the casting (W).
t_{ch} = The time required for chill saturation (sec).
Q_{sh} = The super heat in the casting (W).
Q_s = The latent heat in the casting (W).
R_{st} = The riser solidification time.
t_{rsh} = The time required to remove super heat from the riser (sec).
t_{rs} = The time required for solidification of the riser (sec).
Q_c = The heat transferred from the riser to the mold by conduction (W).
Q_{con} = The heat transferred from the riser to the air by convection (W).
Q_r = The heat transferred from the riser to the air by radiation (W).
A_{side} = The side area of the riser (m^2)
$Atop$ = The top area of the riser (m^2).
h = Convection heat transfer coefficient (W / m^2 K).
ε = The emmissivity.
σ = Stefan-Boltzman constant (W/m^2 K^4).

REFERENCES

1- **E. Paul De Garmo, J. Temple Black and Ronald A. Kohser**, *" Materials And Processes in Manufacturing", 7th edition Macmillan Publications Company, New York, USA, 1990.*

2- **Ruddle R.W., Suchil A. L.**, *" Riser sizing by microcomputer" Eng. foundation conf. on Modeling of casting and welding process II, New York, USA, 31 July - 5 Aug. 1983.*

3 - **Jong Cheon Park, Kunwoolees**, *"Computer aided design of pattern and risers for casting processes ", Vol. 113, PP 59-66, Journal of Engineering for Industry, February 1991.*

4 - **N. Sirilertwoyakul, P.D. Webster, and T.A. Dean**, *"A software package for the design and production of castings", PP 363-369, The Foundryman, October 1993.*

5 - **N. Sirilertwoyakul, P.D. Webster, and T.A. Dean**, *" Computer predication of location of heat centers in castings ", Vol 9, PP 923-928, Materials Science and Technology, October 1993.*

6- **A. Aboul-Nour, T. El-Midany, F. Shehta, A. Ragab**, *"Computer Aided Foundry Mold Design ", Mansoura Engineering Journal (MEJ), Vol.20, No.2, June, 1995.*

7 - **Howard F. Taylor, Merton C. Flemings, John Wulff**, *" Foundry Engineering ", JOHN WILEY & Sons, USA, 1959.*

8 - **D. R. Poirier, E. J. Poirier.** *" Heat Transfer Fundamentals for Metal Casting ", TMS, Pensylivania, USA, 1991.*

9 - **M. Necati Ozisik**, *" Heat Conduction ", JOHN WILEY & SONS, USA, 1980.*