Development of CO_2 Gassing System for Optimized use of Gas in Mould Hardening of Steel Castings

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***Abstract* - In CO_2 mould hardening, once mould cavity is produced, CO_2 gas is passed through it which reacts with sodium silicate to make the mould harder. CO_2 moulding process due to its ability to produce harder moulds is widely used for casting variety of metals and especially high density alloys like steels. The study is focused on development of a system for optimization of CO_2 consumption & process time. In previous practice, the CO_2 from CO_2 cylinder was directly passed into mould at lower temperature than desired & higher pressure due to uncontrolled throttling through air gun which resulted in loss of CO_2, non-uniform mould strength & more process time. To overcome these problems, a gassing system has been developed which reduces CO_2 consumption as well as process time. Also, an automation of the system is proposed to time the gas flow in more efficient manner.**

Keywords: Gassing system, CO_2 moulding, template, CO_2 Consumption, CO_2 properties, flow rate, gassing time.

1. INTRODUCTION

In CO_2 moulding process, CO_2 reacts with the binder i.e. sodium silicate and mould becomes hard. However, the method of passing CO_2 into the mould plays an important role in optimizing this process. The sponsoring company is a manufacturer of Steel Castings (viz. valve bodies). Silica sand moulds are mainly used in the company. Prevalent practice in the company was to pass the CO_2 into the mould directly from CO_2 cylinders through small hoses. The holes were produced arbitrarily in the mould and CO_2 was passed through each hole using air gun. As a result there was no uniform distribution of CO_2 into the mould and the gassing time totally depended on operator's skill/judgement. Also CO_2 losses due to leakage were present. The reaction between sodium silicate and CO_2 is as follows:

$$Na_2O.xSiO_2 + nH_2O \xrightarrow{CO_2} Na_2CO_3.xSiO_2.nH_2O$$

Objectives:

Developing a controlled gassing system primarily to reduce CO_2 consumption and subsequently achieve uniform mould strength through uniform distribution, to optimize both time and cost required for the process. Also eliminate the hazards associated with handling pressurized CO_2 cylinders.

2. LAYOUT DESIGN

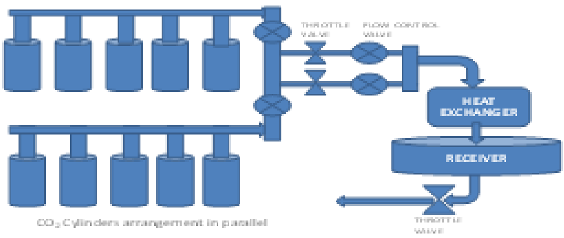

Fig 2.1 Layout of System

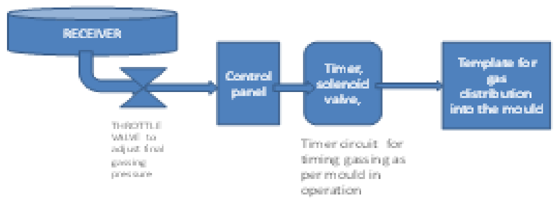

Fig 2.2 Distribution System

In conventional practice, CO_2 from CO_2 cylinder was directly passed through hose pipe into the mould. The cylinder pressure being very high (50-60 kg/cm^2) and if throttled into mould through air gun causing CO_2 temperature to drop below room temperature due to Joule Thompson effect. But the Reaction best occurs at room temperature. So to control the parameters such as pressure, temperature etc as per requirement of reaction, above conditioning system is developed [1]. The high pressure CO_2 from cylinders is passed through copper hoses to the CO_2 manifold. Then the gas is passed through throttle valve followed by flow control valve. The gas pressure is reduced to desired value (1-3 kg/cm^2) after throttling. The temperature of gas drops down to -40^0 C after throttling. But the reaction of CO_2 and sodium silicate is favorable at room temperature. So a heat exchanger is employed to increase the temperature. After that a receiver is used to store the CO_2. After conditioning of CO_2,task is to

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distribute it uniformly into mould cavity, a distribution system is developed for which template is developed. Five anchor bolts of $\phi 8$ mm at suitable positions are fixed and they are connected by CO_2 carrying pipe. The time for which CO_2 gas should be passed (Gassing time) in a standard ,frequently used job is also calculated to optimize CO_2 consumption. An automatic control is proposed to make the process semi-automatic.

3. DESIGN OF HEAT EXCHANGER (EVAPORATOR)

The heat extracted (Q) in heat exchanger is given by

$$Q = h.A.\Delta t$$

After throttling the pressure drops down from 60 kg/cm^2 to 10 kg/cm^2 and it is associated with temperature drop from 25^{o}C (room temp.) to -40^{o}C.

The Log mean temp difference (LMTD) is calculated as:

$$LMTD = \frac{dt1 - dt2}{\ln(dt1/dt2)}$$

For Natural Convection,

For the air velocity range of 0-20m/s, heat transfer coefficient (h) = 40 W/m^{2}K

From psychometric chart, specific volume at 10 bar = 0.038 m^3/kg

Preferred flow rate of CO_2 =1ft^3/min

$$Mass\ flow\ rate\,(\dot{m}) = \frac{Preferred\ flowrate}{Specific\ volume}$$

$$Heat\ transfer\ area, A = \frac{Q}{h \times \Delta t}$$

Type of tube selected - Transverse finned

Tube Material selected - Copper

The maximum working pressure is 10 kg/cm^2. Hence for safety, the system is designed to a pressure of 15 kg/cm^2.

By the use of material and working pressure copper tube is selected from chart.

Let fin O.D = 24mm

$$Fin\ surface\ area = A_f = \Pi/4 \times (fin\ dia.^2 - copper\ tube\ dia.^2) \times 2$$

$$No.of\ fins\ required = \frac{A}{A_f}$$

Now to determine the fin spacing, assuming length of tube = 2.5 m= 98.425 inch

Therefore, $Fin\ spacing = \dfrac{No.of\ fins}{inches}$

$$Actual\ tube\ length = \frac{Calculated\ fin\ spacing}{Actual\ fin\ spacing\ available} \times assumed\ length$$

Design of CO2 Gas Receiver:

Selecting volume as per the requirement & design pressure (P_i) is already known.

Assuming length of cylinder reservoir= l =2*Di

Where Di is internal diameter,

Now, $Di = \sqrt[3]{\dfrac{2V}{\pi}}$

Where, V is the volume of cylinder.

Let material be IS: 2062 GRADE A Structural Steel for Fabrication,

S_{ut} = 410 N/mm^2, FOS = 5

$$Thickness, t = \frac{Pi*Di}{2*\sigma_t}$$

Design of Hose pipe at the outlet of CO_2 cylinder:

Material selected – Copper

Design pressure= 1.5×P_w

Using above data, hose pipe is selected from chart.

Design of Manifold collecting CO_2 gas from cylinders:

Material selected – Brass

Design pressure= 1.5×P_w

O.D is selected from chart. Length required = 3 m (on 2 sides together)

Design of throttle valve & throttle valve line:

Selection based on the manufacturer's catalogue complying with inlet pressure (range) & outlet pressure.

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DESIGN SPECIFICATIONS

Component	Specifications
1. Heat Exchanger	Transverse finned copper tube Tube OD = 12 mm Fin spacing= 26 & Length of tube= 2300 mm
2. CO2 gas receiver	IS 2062 Steel Internal dia.=500 mm length of cylinder= 1000 mm Thickness= 5 mm
3. Hose pipe	Material- Copper OD= 8 mm & Length = 1 m
4. Manifold collecting CO2 gas from cylinders	Material- Brass OD= 16 mm & Length= 3 m
5. Throttle valve	Inlet pressure range= 00-100 kg/cm^2 Outlet pressure range= 0-10 kg/cm^2
6. Throttle valve line	Material- Brass OD= 16 mm & Length= 3 m

Development & Testing of Gassing System:

Based on above specifications conditioning system is developed as below. The conditioning system contains throttle valve, flow control valve, pressure gauge, heat exchanger, receiver, outlet throttle valve etc. And for uniform distribution the template is designed as shown below.

Figure 1: Developed Conditioning System

Figure 2: Distribution Template

The amount of CO_2 required to harden the mould of steel castings per month in prevalent system have been measured for the months of Nov 15, Dec 15 and Jan 16. Similar tests are carried for the modified system also in the months of Feb 16, March 16. Also during the test, overall time required for the operation was measured for both prevalent and modified system and compared.

Gassing Time for each template:

We know sand density and density of steel castings. Also, as per the conventional practice recommended by Indian Foundry, 1 kg of sodium silicate is required for 20 kg of sand and 1 ft^3 CO_2 gas is required per pound of sodium silicate. So CO_2 required per kg of sand can be found out. Then by calculating mass of sand in the mould (in drag), CO_2 required for considered mould can be find out.

For calculating mass of sand in mould,

$$Mould\ volume(drag) = Length \times Breadth \times Depth$$

$$Volume\ of\ sand\ in\ drag = Mould\ volume - Job\ volume$$

$$Mass\ of\ sand\ in\ drag = Volume\ of\ sand \times sand\ density$$

So, amount of CO_2 required can be found.

For gassing time calculation,

$$Average\ CO_2\ flowrate\ per\ template =$$

$$Total\ flowrate\ for\ 20 \times 20\ mould = 4 \times Avg.\ flowrate\ for\ 10 \times 10\ template$$

$$Total\ gassing\ time\ for\ entire\ mould\ (T) = \frac{Amount\ of\ CO_2\ required\ for\ considered\ mould}{Total\ flowrate\ for\ considered\ mould}$$

$$CO_2\ gassing\ time\ per\ template = \frac{T}{4}$$

RESULT & DISCUSSION

1. CO_2 Consumption:

	Month	Melting (kg)	CO_2 (kg)	CO_2 / melting (kg/kg)
Prevalent	Nov 15	175688	9774	0.05563
	Dec 15	118026	6655	0.056385
	Jan 16	93728	5586	0.05959
Improved	Feb 16	80564	3828	0.047515
	Mar 16	117295	5446	.04643

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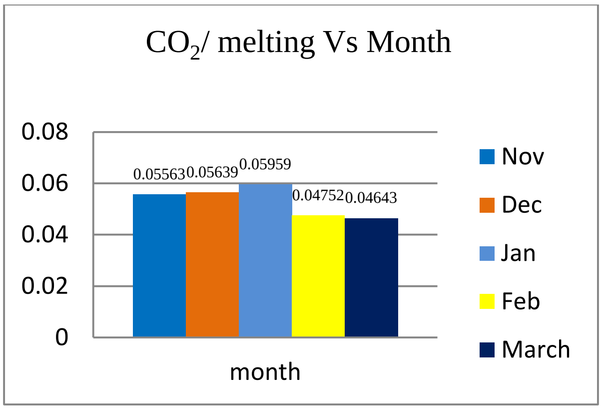

2. Gassing time required (per drag) –
i. Prevalent practice: 4 min 2 sec
ii. Improved method: 2 min 52 sec

CONCLUSION:

With the implementation of new system, CO_2 consumption is reduced by about 18% and thereby reduced cost of CO_2. It is observed that the average monthly savings of CO_2 cost is Rs.11, 966/- which is significant and the payback period is found to be 6.5 months. In addition to that the use of template has shown significant reduction in gassing time and uniform distribution of CO_2. The uniform strength of mould can be achieved by using the standardized template for the CO_2 distribution as designed and implemented in this work. As CO_2 gas always passes through manifolds under controlled conditions, hazards associated with handling CO_2 as well as its leakage is prevented. Also, the improved system has been found to be highly cost effective as indicated by its simple payback period. As gassing time is calculated, arbitrary consumption of CO_2 is avoided which in turn reduces the gassing time. Thus the gassing process is systematically optimized.

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