ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 15
Special Issue
1/2015

41 – 46

9/1

Examination of Gas Flows in Cores About the Changeable Cross-sections Executed in the Cold-box Technology

Ł. Jamrozowicz* J. Zych, J. Kolczyk
AGH University of Science and Technology, Faculty of Foundry Engineering,
Reymonta 23, 30-059 Kraków, Poland
* Corresponding author. E-mail address:ljamroz@agh.edu.pl

Received 28.04.2015; accepted in revised form 05.05.2015

Abstract

The measurement results of the gas pressure in intergranular spaces of fast-setting moulding sands, hardened by a reactive gaseous factor, are presented in the hereby paper. In addition, the new research stand for measuring gas pressure changes in the core of a variable cross-section, during hardening of this core, is shown. The measuring method is also described. Investigations concern determinations and recording of the gas pressure pathways in moulding sands along the core height, in five measuring points. The influence of the hardening gas pressure on the gas distribution in the moulding sand was determined. The influence of the shape change (cross-section) of the core on the character of changes of the hardening gas pressure in the core being hardened, was also shown. The hardening gas of a constant pressure was fed continuously into the core.

Keywords: Cold-box process; Fast-setting sands; Carbon dioxide; Pressure

1. Introduction

Compacted moulding sand is a porous medium in which pore sizes – intergranular spaces, depend on the matrix grain size, it means on the coarseness, grain shapes, binder amounts added to a sand and also on its compaction. Gas flows through such medium is relatively not well recognised.

Until now only a few scientists were dealing with the effect of filtration of porous media. To the best known belongs Henry Darcy [1], who - on the experimental bases - developed the equation concerning the dependence between the filtration rate and gas pressure. However, Darcy did not take into account the fluid (gas) viscosity. In subsequent years the Darcy equation was improved in such a way as to take into account the viscosity of the flowing fluid. Equation 1 presents the scalar formulation of the Darcy Law [1]:

$$u = -\frac{k}{\mu}\frac{\Delta p}{l} \tag{1}$$

where:
u - filtration velocity – flow through a porous medium,
Δp – pressure drop,
l - height of a porous layer,
μ - viscosity of the flowing liquid,
k - permeability of a porous layer.

Since the fluid flow occurs according to the pressure decrease the sign minus is seen in this equation.

Intergranular pores occurring in compacted moulding sands are similar to capillaries. Hagen and Poiseuille were dealing with gases (fluids) flowing through capillary channels and formulated the law describing the gas transport in the porous medium - the gas flow rate. Equations 2 and 3 provide the mathematical description of this law [4,5].

$$\overline{\upsilon} = \frac{D_p^2 \cdot \Delta P}{32 \cdot \eta \cdot L} \tag{2}$$

$$\overline{\upsilon} = \frac{V_p^2 \cdot V_l \cdot \Delta P}{(1-V_p)^2 \cdot S^2 \cdot \eta \cdot 2L} \tag{3}$$

gdzie:
$\overline{\upsilon}$ - flow rate of gas
ΔP – pressure difference
η - gas viscosity
V_p – porosity scale of a medium
D_p – intergranular capillaries size
L – length of capillary channels
S – surface area of pore walls

Not much studies, devoted to mathematical models describing a gas flow through granular, porous medium such as compacted moulding sand, can be found in the world literature. One of the authors presenting mathematical models related to a flow - permeation - of gases through porous media is Kaczmarek. However, in his papers [2, 3] he is dealing with porous rocky media, which due to conditions of the process and applied assumptions can not be used for the description of gases flows through compacted moulding sands.

Based on Kaczmarek models, Jamrozowicz [6,7] proposed the mathematical description of the gas flow through a porous medium. Equation 4, after establishing the boundary conditions, can be used for modelling pressure changes in a core.

$$\frac{\partial p}{\partial t} - \frac{k}{\varepsilon\mu} * \frac{\partial}{\partial x}\left(p * \frac{\partial p}{\partial x}\right) = 0 \tag{4}$$

where: p - pressure, k - mass permeability, ε - mass porosity
μ - dynamic viscosity of gas

Equation 4 is correct for neutral gases, it means for gases which during flowing are not used in the moulding sand hardening process. For gases taking part in the moulding sand hardening process (which are used up during the process), it means for reactive gases the mathematical model of gas pressure changes during its flow through the sand, is much more complicated. During the hardening process carried out by the reactive gas its flow (pressure distribution in a moulding sand) will depend on:

- factors related to a sand: compacting degree, matrix grain size, binder amount;
- factors related to a gas: pressure value of the introduced factor and its viscosity;
- advancement degree of the hardening process.

In order to recognise how the reactive gas pressure is changing in the moulding sand during its hardening process, measurements of the pressure in the core were performed during the moulding sand hardening and the influence of the selected factors on this process proceeding was determined.

2. Own investigations

2.1. Purpose and the investigation methodology

In order to perform investigations of gas flows in the core, during its hardening, the new research stand was built. This stand is schematically presented in Figure 1.

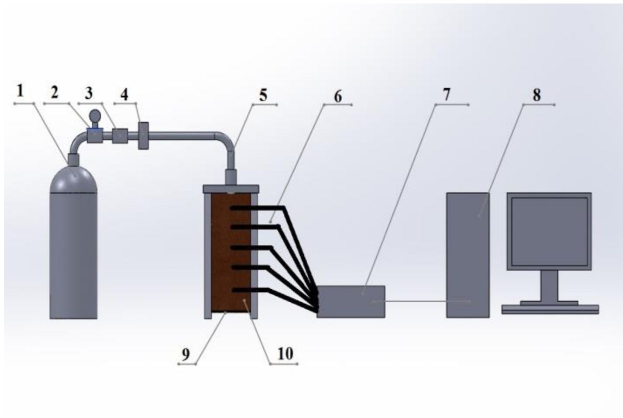

Fig. 1. Schematic presentation of the experimental stand for Investigations of gas flows in cores
1- gas cylinder, 2 - reducer, 3 - heater, 4 – control valve, 5 - place gas dosing, 6 – pressure sensors, 7 - transducers and recorder Agilent, 8 - computer, 9 – perforated bottom, 10 – core box,

To be able to perform measurements of pressure changes of the reactive gas, during the moulding sand hardening process, five holes were drilled in the side wall of the core box. Holes are arranged in such way as to enable measurements in the core axis along its whole length. The measuring points are separated from each other by a distance of 5 cm. The first hole is at a distance of 2.5 cm (measuring point 1) from the place of gas supplying. Figure 2 shows the distribution of measuring points, while Figure 3 presents the core box from the side and the place of gas feeding to the core box.

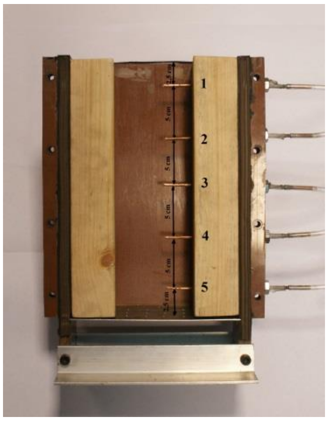

Fig. 2. The distribution of measuring points in core box

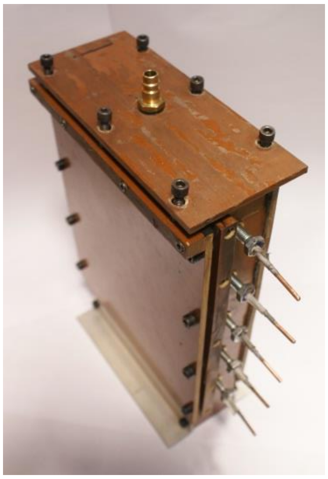

Fig. 3. the core box from the side. Mounting method of sensors

When preparing the core box for measurements, at first the moulding sand was compacted, then blanking plugs were removed and pressure sensors screwed into the holes. Sensors were connected by a cable with pressure converters. The measured pressure value was recorded in the computer via the device Agilent. The recording frequency was three measurements for a second for each measuring point.

To measure pressure in cores of variable cross-sections, special inserts providing the proper shape, were mounted in the core box. The core box with the assembled inserts is presented in Figures 4 – 5.

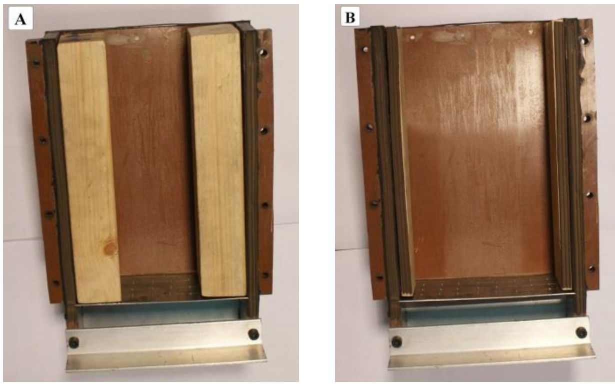

Fig. 4. The core box with the assembled inserts (A) „narrow" core and (B) "wide" core

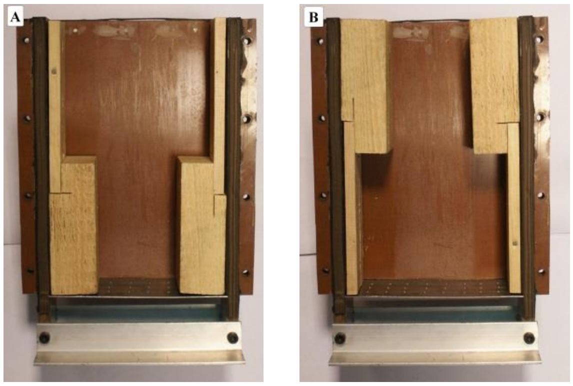

Fig. 5. The core box with the assembled inserts: (A) the core, which cross-section at a half of its height is decreased twice, (B) the core which increases twice its cross-section at a half of its height

2.2. Types of the performed investigations

Moulding sands made on the matrix of high-silica sand "Szczakowa" of the Sibelco Company of the average grain size, were tested:

- d_L = 0,24 mm - "fine" sand;
- d_L = 0,31 mm - "medium" sand;
- d_L = 0,39 mm - "coarse" sand

Water glass R-145 was used as a binder. 5% of it was added. The made cores were blown by CO_2, at a pressure of: 0.25, 0.5 and 1.0 atm. The gas feeding time was constant and equal to 5 minutes.

During the moulding sand hardening process by a gaseous factor changes in the core gas pressure were recorded. Measurements were made - for cores of variable cross-sections - along the core length.

2.3. Gas pressure distribution in the core box during the hardening process

Pathways of gas pressure changes in the core during its hardening are presented in Figure 6. Pressure **p** recorded by sensors, is „de facto" the difference between the pressure in the core - in intergranular spaces and the pressure in the surroundings.

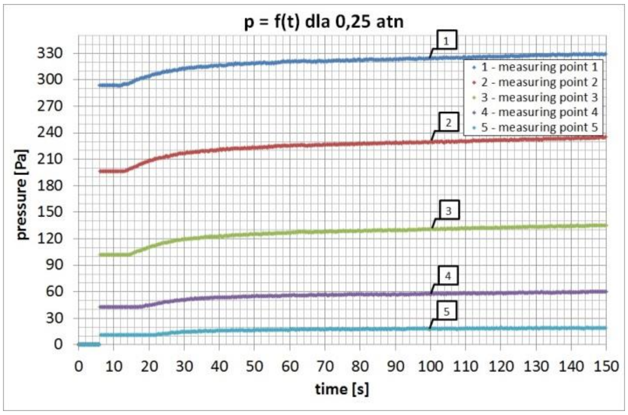

Fig. 6. Pathways of gas pressure changes in the core during its hardening. Sand grains - quartz sand d_L = 0,24 mm , binder - water glass, hardener - CO_2, p_g = 0,25 atn ($25*10^3$ Pa)

The pathway of the pressure changes of the hardening gas in the core, regardless of the measuring point, is similar. Up to the 6-th second of the measurement the pressure in the core is equal to the outside pressure, p = 0. In the moment of starting gas supplying - the 6-th second of measurement - the pressure is growing in each measuring point. From this moment the core hardening process starts. As the result of the reactive gas flow the pressure observed in the core becomes higher than outside, the positive gauge pressure occurs. This positive gauge pressure is not constant. The character of its changes, in each measuring point, can be divided into three periods. In the first period, immediately after gas feeding starts, this pressure stabilises at a certain value and remains constant for some time. Its value depends on the place of measuring, the nearer venting points (it means further away from the blow-holes) the lower positive gauge pressure. The recorded positive gauge pressure is probably related to pushing out a 'compressed' air from intergranular spaces by the hardening gas. The stabilisation of the positive gauge pressure in this period is probably caused by a laminar hardening of the moulding sand. The more distant from the place of gas feeding the longer is this period. In the moment when the hardening gas reaches the given layer its hardening starts and the positive gauge pressure of this gas is observed. The amount of the reactive gas fed in the time unit is the same (it results from the constant pressure of the supplied gas). In the initial period of hardening the majority of the gas fed to the moulding sand layer reacts with a binder due to which the initial value of the positive gauge pressure is lower than its value when the core is fully hardened. The pathway of the positive gauge pressure increase is not linear but similar to the pathway of the moulding sand hardening observed by means of the ultrasound technique. The third period is the stabilisation time of the positive gauge pressure. The hardening process of the moulding sand in the given layer is finished. The positive gauge pressure will be the result of the moulding sand permeability and pressure of the supplied gas.

2.4. Influence of the supplied gas pressure on the pathways of the pressure in the core

The influence of the supplied gas pressure on the pressure changes pathways in the core, during its hardening, is presented in Figures 7 and 8.

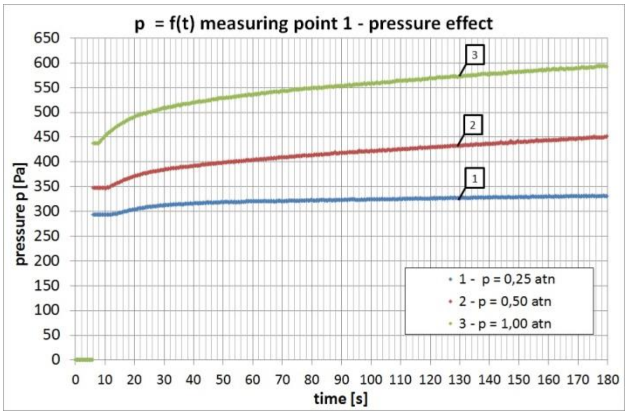

Fig. 7. The influence of the supplied gas pressure on the pressure changes pathways in the core, during its hardening – measuring point 1. Sand grains - quartz sand d_L = 0,31 mm , binder - water glass, hardener - CO_2

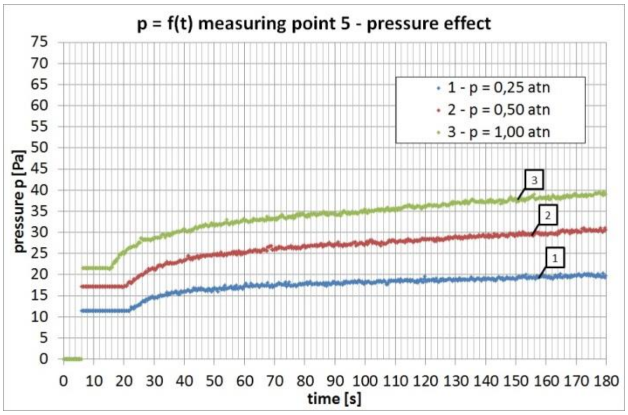

Fig. 8. The influence of the supplied gas pressure on the pressure changes pathways in the core, during its hardening – measuring point 5. Sand grains - quartz sand d_L = 0,31 mm , binder - water glass, hardener - CO_2

It can be noticed - from the diagrams - that regardless of the fed gas pressure the pressure pathway inside the core is similar, but some differences can be seen. Regardless whether we observe pathways in measuring point 1 (it means 2.5 cm from the place of gas supplying) (Fig. 7) or in measuring point 5 (it means 2.5 cm from venting holes) (Fig. 8), the higher pressure of the supplied gas the higher positive gauge pressure inside intergranular spaces. The second difference between pathways constitutes a 'delay' time in starting the hardening process. The higher pressure of the supplied gas, the smaller 'delay'. E.g. in measuring point 1 for pressure p_g = 1 atn the moulding sand hardening process, observed by an increase of the positive gauge pressure, starts after 2 seconds from the moment of starting the gas supplying, while for pressure p_g = 0.25 atn it starts barely after 8 seconds. The third observed difference is the growth intensity of the positive gauge pressure. This growth is more intensive for pressure p_g = 1 atm. than for pressure p_g = 0.25 atn. This fact can indicate that in the first case (p_g = 1 atn.) the hardening process of the moulding sand occurs with an excess of CO_2, while in the second case (p_g = 0.25 atn.) with a shortage of CO_2. Too intensive performing of the hardening process, especially when water glass is applied, can cause a lack of a relaxation of stresses during the binder hardening, which - in turn - can lead to breaking bridges binding matrix grains, it means to weakening of the core strength.

2.5. Influence of the core shape on the pressure changes

Figure 9 presents the comparison of pathways of the pressure changes in cores of various cross-sections. The core described as 'wide' has two times larger cross-section than the core described as 'narrow'. The cross-section area is constant at the core whole length.

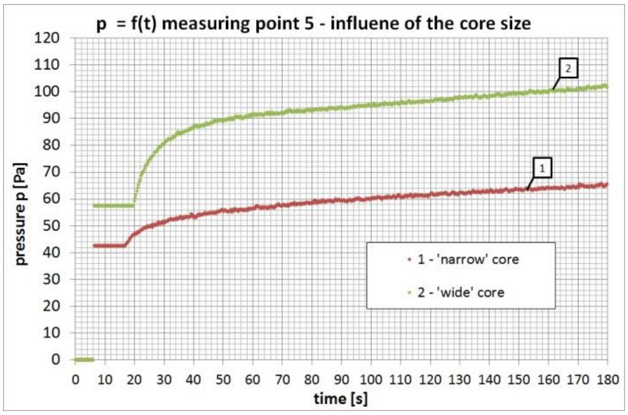

Fig. 9. Pathways of the pressure changes in cores of various cross-sections, during its hardening – measuring point 5. Sand grains - quartz sand d_L = 0,31 mm , binder - water glass, hardener - CO_2, P_g = 0,50 atn

The pathways of changes of the positive gauge pressure in cores of different cross-sections presented in Figure 9 indicate certain differences. In the first place, a delay in starting the hardening process of the given moulding sand, is longer for the 'wide' core than for the 'narrow' core. The gas fed to the cores was of the same pressure, which means that a longer delay for the 'wide' core was due to a larger amount of moulding sand to be hardened. Thus, the hardening process of the given layer will last longer. However, the hardening time is not twice longer when the moulding sand amount to be hardened is twice as large. This non-linear dependence, between the moulding sand amount and the hardening time, is probably due to the fact that for the core of a larger cross-section ('wide') a higher positive gauge pressure occurs and the hardening kinetics is faster, which causes a faster gas transport and the acceleration of the hardening process.

The comparison of the pressure changes observed in the 5-th measuring point in cores of variable cross-sections along their height, is presented in Figure 10. For the easier description the name 'wide – narrow' will be used for the core, which cross-section at a half of its height is decreased twice (Fig. 5A). While the name 'narrow – wide' will be used for the core which increases twice its cross-section at a half of its height (Fig. 5B). In both cases the same amount of the moulding sand was compacted in the core box. The detailed analysis of the diagram allows to notice certain differences which indicate that the way of the core placement in the core box is important and influences the hardening process. For the 'wide – narrow' core the higher positive gauge pressure and shorter delay period is observed and the hardening process is more intensive. Such placement of the core, it means the smaller cross-section area near the blow hole while the larger near venting holes, causes shorter hardening time than in the opposite case.

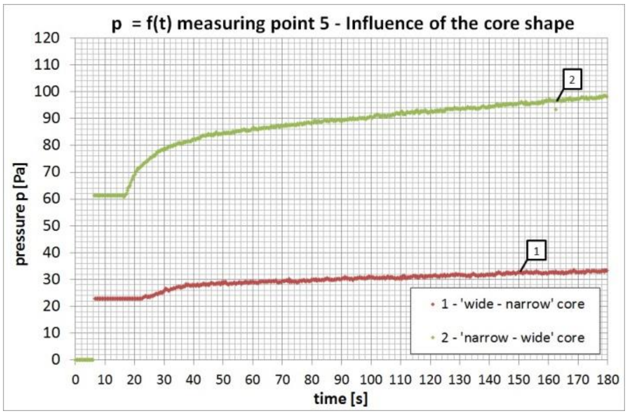

Fig. 10. Influence of the core shape on the pressure changes – measuring point 5. Sand grains - quartz sand d_L = 0,31 mm , binder - water glass, hardener - CO_2, P_g = 0,50 atn

3. Conclusions

Investigations of gas pressure changes performed in the core during its hardening allow to present the listed below conclusions.

- Pressure of the hardening gas, inside intergranular spaces during the hardening process is not of a constant value despite a constant pressure of a gas fed from the cylinder. In the initial phase the gas pressure is constant. As the hardening progresses, when a 'demand' for the gas decreases, the pressure gradually increases. When the hardening in the given micro-zone is finished the pressure obtains the constant and maximum value.
- The pathway of the pressure changes in the core (in the given layer) is similar to the pathway of the hardening process obtained by means of the ultrasound technique.
- The farer from the gas feeding point the longer time after which the positive gauge pressure grows. This indicates a

laminar hardening process - along the core height - of the moulding sand.

- The higher pressure of the gas fed to the core the higher positive gauge pressure in intergranular spaces and the shorter hardening time.
- The core shape and its position in the core box influences pathways of pressure changes in intergranular spaces and in consequence the hardening process time.

Acknowledgements

The research was performed within the deans grant AGH Kraków Nr: 15.11.170.509

References

[1] Darcy, H. (1856). *Les fontaines publiques de la ville de Dijon*, Dalmont, Paris.

[2] Kaczmarek, M. (2008). Aproximate Solution for Non-stationary Gas Permeability Tests, *Transport Porous Media* 75. 151 – 165.

[3] Kaczmarek, M. (2010). Modeling reservoir gas permeability tests for cylindrical and spherical geometry. *Transport in Porous Media* 84: 95-108

[4] Zych, J. (2002). The setting kinetic of moulding sands with water glass. *Acta Metallurgica Slovaca*, t. 8. nr 2. 93-98.

[5] Zych, J. & Jamrozowicz, Ł. (2010). Advancement of the hardening front in forms and cores made of quickly bonding composites - ultrasonic analyses. *Archives of Metallurgy and Materials* 55(3). 963-968.

[6] Zych, J. & Jamrozowicz, Ł. (2011). The change of the gas pressure in cores made in cold-box technology during their hardening. *Archives of Foundry Engineering*. vol. 11 iss. 4, 204–208.

[7] Jamrozowicz Ł. (2013). Influence of the gas dosage method on pressure changes and technological properties of core sand used in the technology resol−CO_2. *Archives of Metallurgy and Materials*. vol. 58 iss. 3. 891–894.