BLOCKING PHENOMENON OF ICE/WATER SLURRY AT THE TUBE ORIFICE

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It is suggested that the cohesive nature of ice-particle is the main cause of the blocking of ice/water slurry. However, very few works have been carried out so far on the ice particle blocking and no data is reported on the cohesion force of the ice particles in water to be correlated with this phenomenon. The specific aim of this work is to clarify the mechanism of the blocking of ice/water slurry flow at an orifice in a pipeline and to find a criterion for the occurrence of the blocking of ice/water slurry.

INTRODUCTION

A new cold energy transportation system utilizing ice/water mixture flow is under development for the purpose of raising cold energy density in district cooling systems. Many experimental works[1-2] have been carried out to clarify the flow and heat transfer characteristics of ice/water slurry and to develop devices and instruments to be applied to the system. As a result of these works, it is reported that the blocking of pipe elements such as a reducer, valve and distribution manifold is likely to occur due to the compressed ice particle clusters. This type of blocking is quite different in the nature from blocking due to the arching or the deposition observed in usual solid-particle/water slurry transportation pipelines.

EXPERIMENTAL APPARATUS AND PROCEDURE

The experiment for blocking was composed of the element test using the apparatus shown in Fig.1 and the pipeline test. In the former, ice-particle/water mixture filling a transparent pipe was driven out through the test orifice by a piston-cylinder device. The blocking process was observed and recorded by video. Fig.2 shows the details of test section. Pressures p_1 and p_2 at the locations in Fig.2 and the ice fraction C upstream the orifice were detected. Electrodes for ice fraction measurement were attached at the position A. The electrodes were removed for the observation test. This test section was used in the pipeline test, too. Four classes of particles were used as the sample: chip ice (mean particle size d_p=10mm, ρ=917kg/m^3), granulated snow (d_p=3mm, ρ=917kg/m^3), fresh snow (d_p=1mm, ρ=917kg/m^3) and polypropylene beads (d_p=4mm, ρ=908kg/m^3).

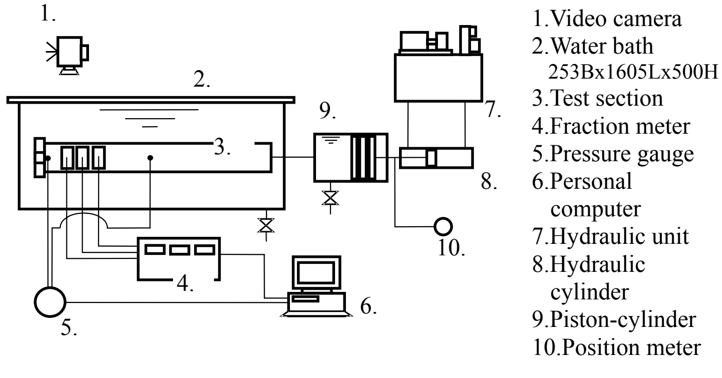


Fig.1 Schematic diagram of apparatus for the test element

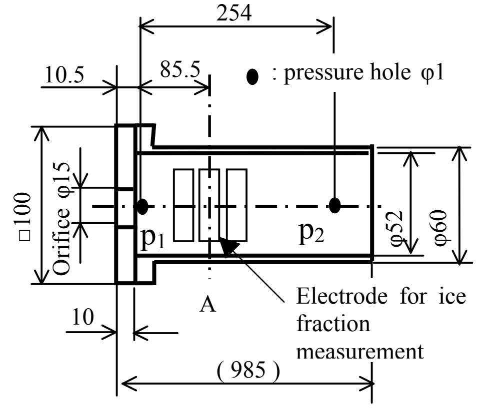


Fig.2 Details of test section

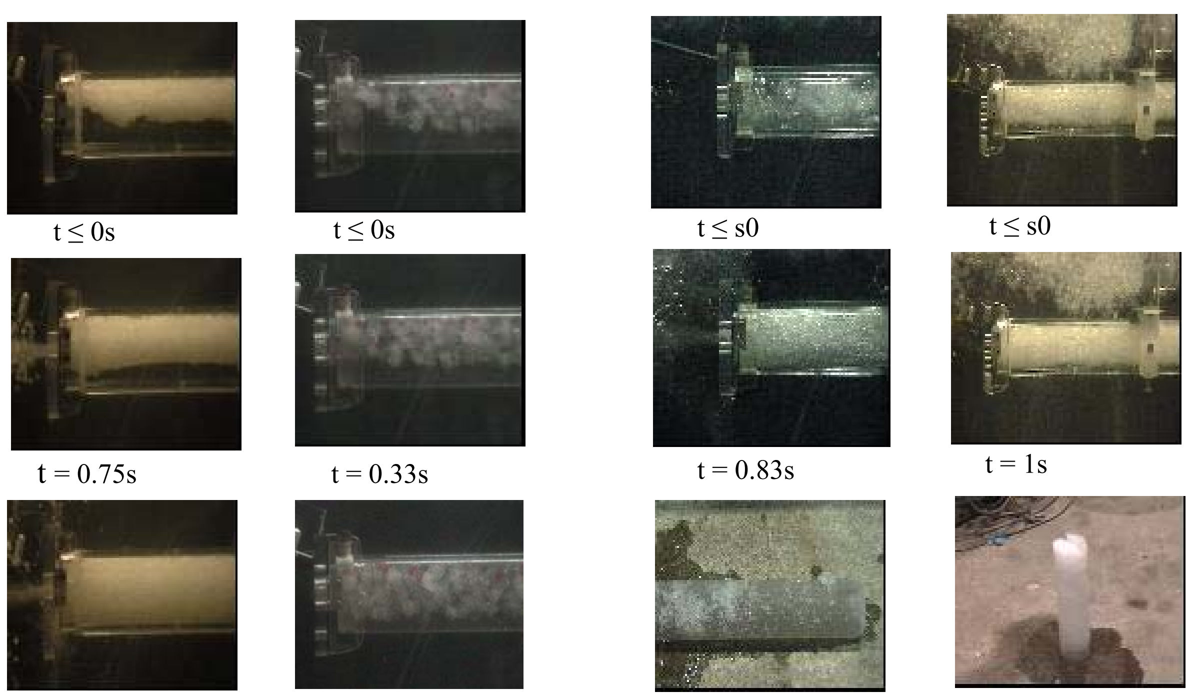
Test particles were weighted and put into the test section uniformly along the pipe axis. The range of the velocity *u* is 0~1m/s, and initial particle fraction C_0 is 0~32%. The compressive yield stress of each ice particle was measured by adding a load abruptly to the cylindrical test piece (a cluster of particles with diameter 65mm and length 65mm).

RESULTS AND DISCUSSIONS

Photographs in Figs 3a & 3b show the blocking of the beads and the chip ice slurries, respectively. In the case of these non-cohesive particles, the particle fraction C increases steeply and soon attains a constant value nearly equal to that of the natural packing. When the orifice diameter d_o was larger than a certain critical value, i.e. d_o>10 mm for the beads and d_o>25mm for the chip ice, no blocking occurred, irrespective of the initial fraction C_o and the flow velocity *u*. The particle cluster could not keep its shape and the particles separated from each other when removed out of the test pipe. Hence, the blocking of these particles was considered to be caused by the arching.

In the cases of the fresh snow and granulated snow, the blocking occured when d_o<15 mm, as seen in Figs. 3c and 3d. The fraction C and the pressure difference p_2-p_1 increased gradually after a small snow particle cluster stagnated at the orifice until a plug-like particle cluster filling the pipe was formed. The particle-plug had considerable strength like a solid column as seen in the bottom frames of photographs in Figs.3c & 3d. Hence, we call this type of blocking "compressed plug type blocking".

Since the cohesive nature of ice particles in water is considered to be a governing factor for the compressed plug type blocking, it is estimated by the compressive yield stress obtained through a compression test on a cylindrical particle cluster sample in water. The ratio of the maximum



t ≤ 0s | t ≤ 0s | t ≤ s0 | t ≤ s0

t = 0.75s | t = 0.33s | t = 0.83s | t = 1s

t = 2s | t = 0.83s | produced cluster | produced cluster

(a) Beads u=0.42m/s,C_0=35% (b) Chip ice u=0.13m/s,C_0=25% (c) Granulated snow u=0.18m/s,C_0=35% (d) Fresh snow u=0.13m/s,C_0=31%

Fig.3 Blocking at orifice (← flow direction) orifice diameter for the blocking to the particle size is plotted against the compressive yield stress in Fig. 4. This result infers that the cohesive nature of the particles is the dominant factor for the blocking.

The criterion for the compressed plug blocking of the granulated snow obtained through the element test is presented in Fig.5a as a curve on the u-C_o plane. At a velocity u lower than a certain value, stagnation of the particle cluster occurs for the lowest value of C_o. Since the stagnation may lead to the blocking if the orifice is installed in a pipeline for the cold energy transportation, this velocity is taken as the threshold for the non-blocking condition. In the case of the fresh snow, the threshold value of u is higher as seen by comparing Figs.5a and 5b.

The blocking was examined on the orifice in a pipeline of a slurry transportation system, and the results are compared in Fig. 5 (b) with those of the element test. The criterion curve by the latter seen to present the condition for the occurrence of the blocking of ice/water slurry in a pump-pipeline system.

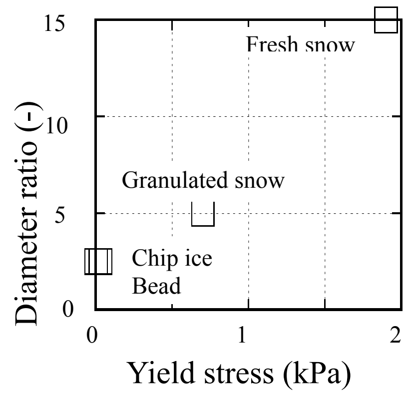


Fig.4 Blocking diameter ratio

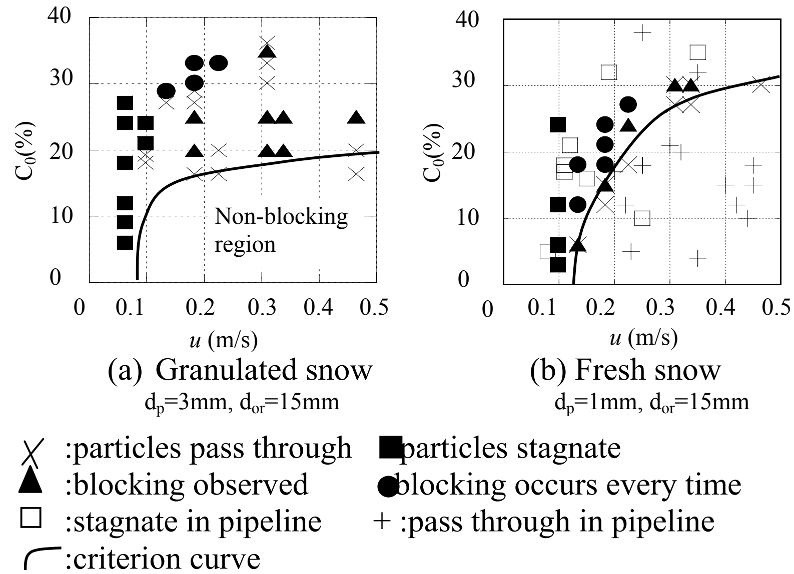


Fig.5 Blocking condition

CONCLUSIONS

(1) The main cause of compressed plug type blocking is the cohesive nature of ice-particle.
(2) The critical curves of blocking at the orifice are introduced in the element test.
(3) The critical condition for the blocking in a pipeline system agrees well with the criterion obtained by the element test.

REFERENCES

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