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Experimental and theoretical study of the effectiveness of the production of hydrogen by steam conversion of methane using circulating fluidized bed technology☆,☆☆

A.M. Dubinin, S.E. Shcheklein, V.G. Tuponogov, M.I. Ershov, Y.A. Kagramanov*

Ul, Sofyi Kovalevskoy, 5, Ekaterinburg, 620002, Russia

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ABSTRACT

The catalytic filling impeded two-chamber circulating fluidized bed reactor meant for methane steam reforming synthesis gas production has been described. Experimental data conform satisfactorily with the process simulation.

Optimum parameters of the analysed reactor were found on the basis of the heat balance equations, set for two chambers and the dependence between methane steam reforming products equilibrium concentrations and temperature with the ratio of CH_4:H_2O = 1:1.

Introduction

Hydrogen is used for the production of ammonia and fertilizers, in internal combustion engines, and in uranium ore recovery [1–3].

The catalytic conversion of methane by water steam in a heated pipe is carried out most often for the production of hydrogen [4]. In this publication, a dual-chamber reactor with a circulating fluidized bed inhibited with catalytic granules is used for this purpose.

Getting the necessary heat by the combustion of natural gas in one chamber and transferring it by inert solid particles into another one designed for converting methane by the water steam and heating the reaction products can be used for the preparation of the syngas (a mixture of hydrogen and carbon oxide).

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☆☆ Ural Federal University named after the first Russian President B.N. Yeltsin

* *Corresponding author*. Tel.: +7 902 442 15 47; fax: +7 (343) 375 95 08.
E-mail address: s.e.shcheklein@urfu.ru (S.E. Shcheklein).

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Nomenclature

t	temperature, °C
x	methane portion supplied for the conversion, m^3/m^3
r	volume the syngas components concentrations, m^3/m^3
q	heat, heat losses; kJ/kg, relative units
c	specific heat capacity, kJ/kgK
a, b, h	substitute variables; kJ/kgK, kJ/kgK, kJ/kg
z	height of the catalytic granules bed, m

Greek letters

μ	relative flowrate of the intermediate coolant, kg/kg

Superscripts and subscripts

1	combustion chamber (q), conversion chamber (t)
2	conversion chamber(q), combustion chamber (t)
3	losses with the chemical incomplete combustion
5	losses to the environment
ng	natural gas
air	air
cor	electrocorundum
cmb	combustion products
cnv	conversion products
s	water steam
ht	heat transfer
H_2	hydrogen
CO	carbon monoxide
CH_4	methane
CO_2	carbon dioxide
H_2O	water
Opt	optimal parameter

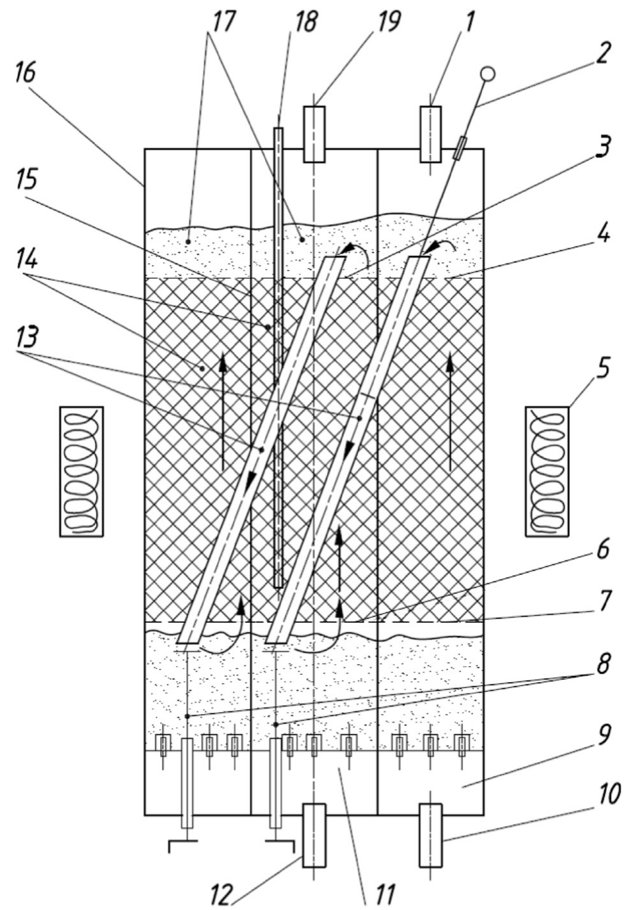

Fig. 1 – The reactor with inhibited circulating fluidized bed for the steam conversion of natural gas. 1 – stub pipe to remove full combustion products; 2 – feeler for measuring the velocity of the released movement of the coolant; 3, 4 – upper grates in the chambers of conversion and combustion; 5 – heat insulation; 6 – support grid in the chamber conversion; 7- catalyst supporting grid in the combustion chamber; 8– baffle plate; 9 – gas–air grid; 10 – stub pipe for supplying gas-air mixture for combustion; 11 – steam and gas grid; 12 – stub pipe for the gas mixture on the conversion; 13 – overflow pipes; 14 – catalytic granules; 15 – wall of the chamber of the steam conversion of methane; 16 – wall of the combustion chamber; 17 – fluidized bed of electrocorundum particulate; 18 – tube for measuring the temperature along the height of the chamber of conversion; 19 – stub pipe for removing products of the steam conversion of methane.

Experimental system

The principal scheme of the reactor is presented in Fig. 1. Both chambers are filled with the cylindrical granules from the catalyst KSN-2 with the particle size of 15 × 15 mm, stable to abrasion resistance and disperse intermediate heat transfer, viz., electrocorundum with the size of 500 μm. Due to the difference of hydraulic resistances of the column of solid electrocorundum particles, descending in overflow pipes 13 and the circulating fluidized bed inhibited by the catalytic granules of the same height, the stable directional circulation of the solid particles of the heat carrier between the chambers is established.

The electrocorundum particles heated in the combustion chamber falls in the overflow pipe under the chamber of conversion. Moving between the catalytic granules in the direction of movement of the gas–vapour mixture (i.e., up), particles give heat to endothermic reaction, heating conversion products. Further, cooled particles in the overflow pipe fall again under the annular combustor for further heating.

The flowrate of electrocorundum particles was regulated by baffle plate 8, and determined the product of the speed of lowering movement of the feeler 2, area of the overflow pipe 13 and bulk density of electrocorundum. The temperature according to the height of the chamber of conversion was measured by the thermocouple placed in the tube 18 at the lower end and located in the catalyst bed. The composition of syngas of steam conversion of the full combustion at the exit