Simulation of 1-D Heat Distribution in Heavy Oil Reservoirs During Steam Injection Process

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INTRODUCTION: Thermal Enhanced Oil Recovery (TEOR) is the main EOR method applied to produce from heavy oil and bitumen reservoirs [1]. In this study we will investigate heat propagation inside the formation during steam flooding and the parameters that affect heating up the reservoir to optimize the process in the future.

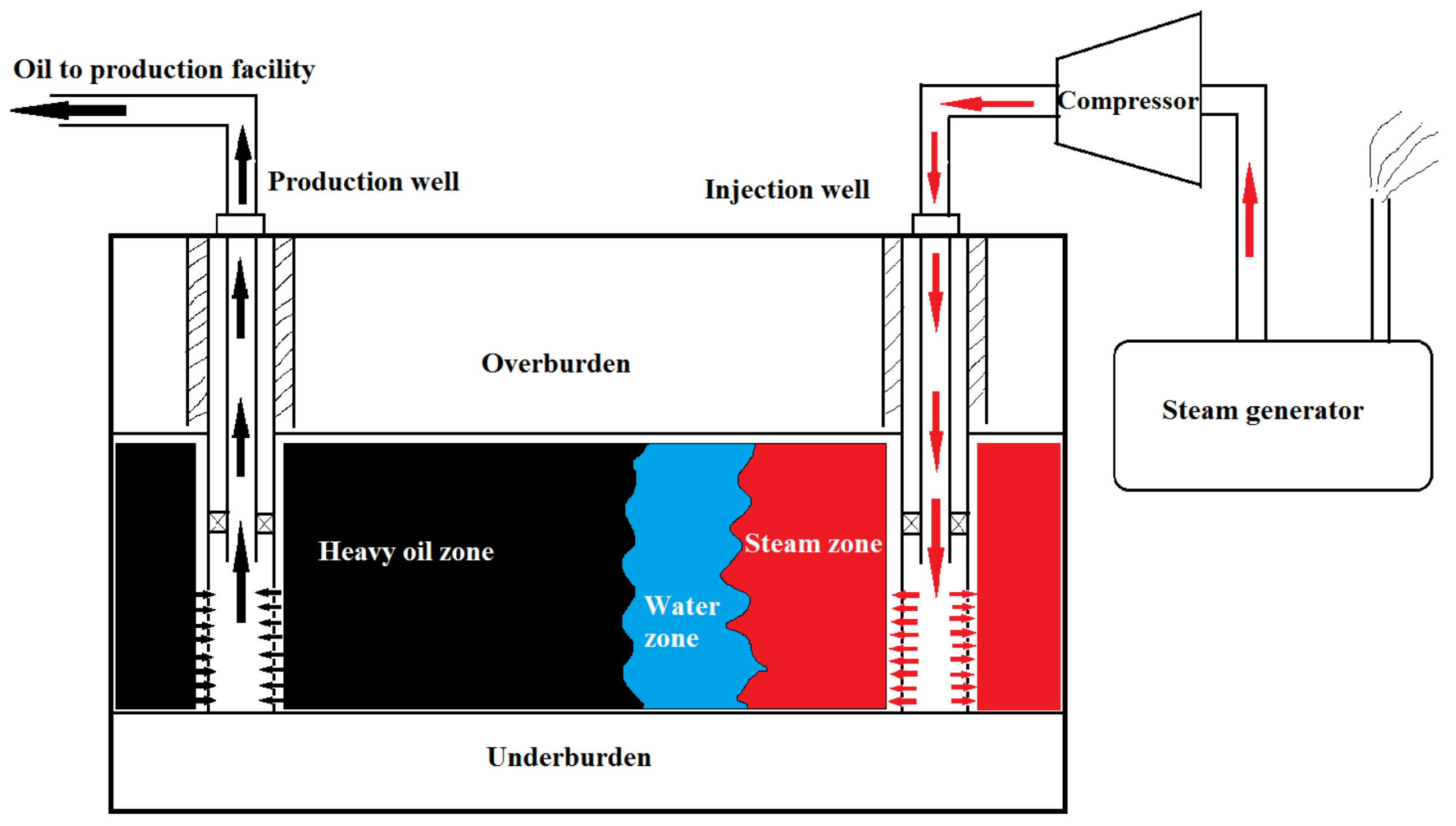

Figure 1. Typical steam injection process in a heavy oil/bitumen reservoir

COMPUTATIONAL METHODS: Energy equation in one dimension for fluid and matrix has been solved in dimensionless form (*eq. 4*) after combining matrix and fluid energy equations (*eq.1 & eq.2*) both (*eq.3*) assuming local thermal equilibrium (LTE) between the fluid and the matrix $T_s = T_f = T$.

Energy equation for matrix:

$$(1-\varphi)\,(\rho c_p)_s\,\frac{\partial T_s}{\partial t} = (1-\varphi)\,\nabla.(k_s \nabla T_s) + (1-\varphi)\,q_s''' + h\,(T_f - T_s) \ldots\ldots(1)$$

Energy equation for fluid within the pore channels:

$$\varphi(\rho c_p)_f\,\frac{\partial T_f}{\partial t} + (\rho c_p)_f\,u\,\nabla T_f = \varphi\,\nabla.\left(k_f \nabla T_f\right) + \varphi\,q_f''' + h\,(T_s - T_f) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$m\,\frac{\partial T}{\partial t} + (\rho c_p)_f\,u\,\frac{\partial T}{\partial x} - k_m\,\frac{\partial^2 T}{\partial x^2} = 0 \ldots\ldots\ldots.(3)$$

$$\frac{\partial T^*}{\partial t^*} + \frac{(\rho c_p)_f\,u^*}{m}\,\frac{\partial T^*}{\partial x^*} - \frac{k_m}{m\,L\,u_i}\,\frac{\partial^2 T^*}{\partial x^{*2}} = 0 \ldots(4)$$

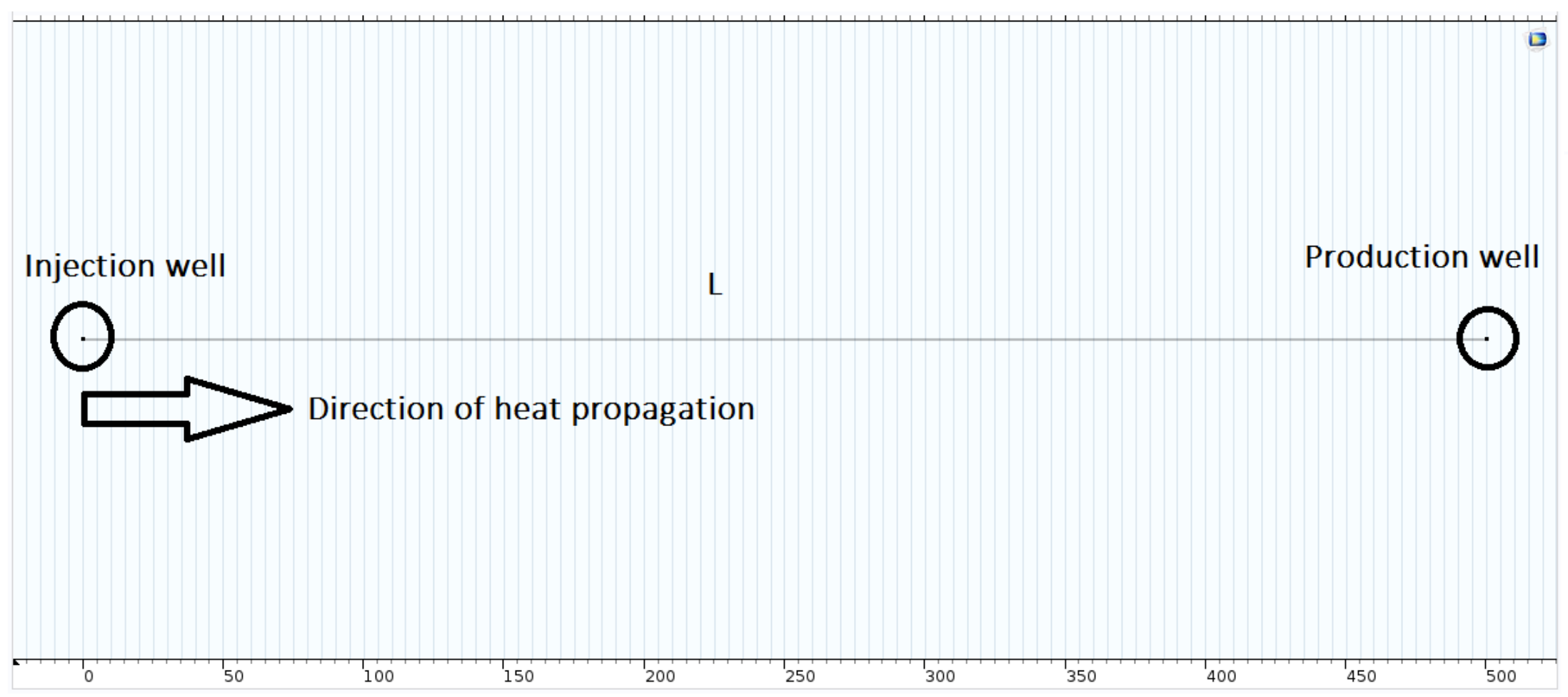

Figure 2. One dimensional simulation domain which contains injection and production wells

Parameter	Value	Parameter	Value
φ	25 %	k_o	0.387 W/m. K
μ_f	10 Pa. s	k_s	2.6 W/m. K
ρ_g	16.7 kg/m^3	k_w	0.6 W/m. K
ρ_o	800.9 kg/m^3	S_g	20 %
ρ_s	2675 kg/m^3	S_o	60 %
ρ_w	1001 kg/m^3	S_w	40 %
C_{pg}	29.7 kJ/kg. C	K	100*10^{-15} m^2
C_{po}	2.1 kJ/kg. C	T_{steam}	260 C°
C_{ps}	0.88 kJ/kg. C	$T_{initial}$	78 C°
C_{pw}	4.2 kJ/kg. C	L	500ft =152.5 m
k_g	0.004 W/m. K		

Table 1. Properties of fluids and rock applied in the model

RESULTS: COMSOL® Mathematics is used

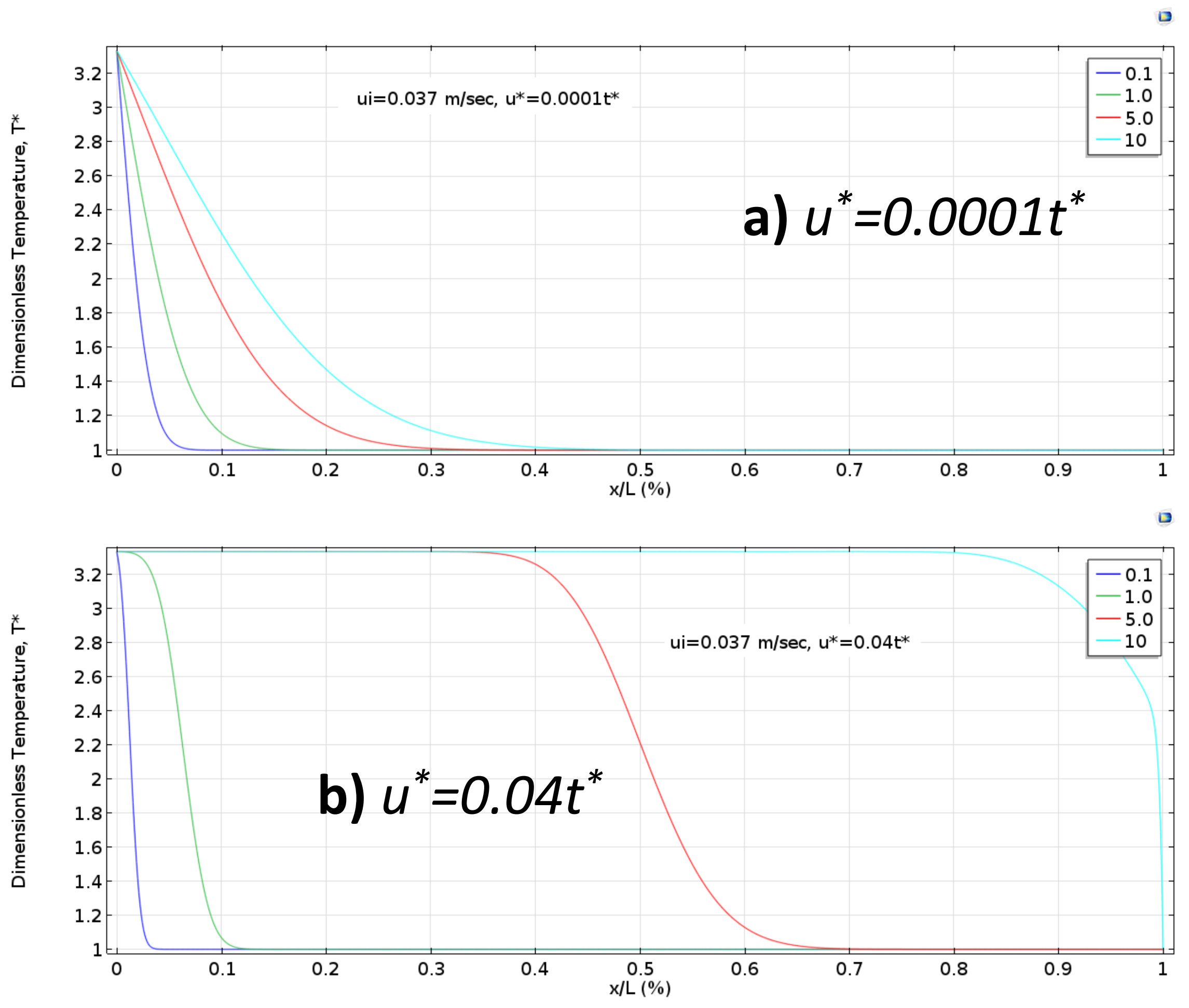

Figure 3. Dimensionless temperature versus dimensionless distance at two different dimensionless velocities a, b

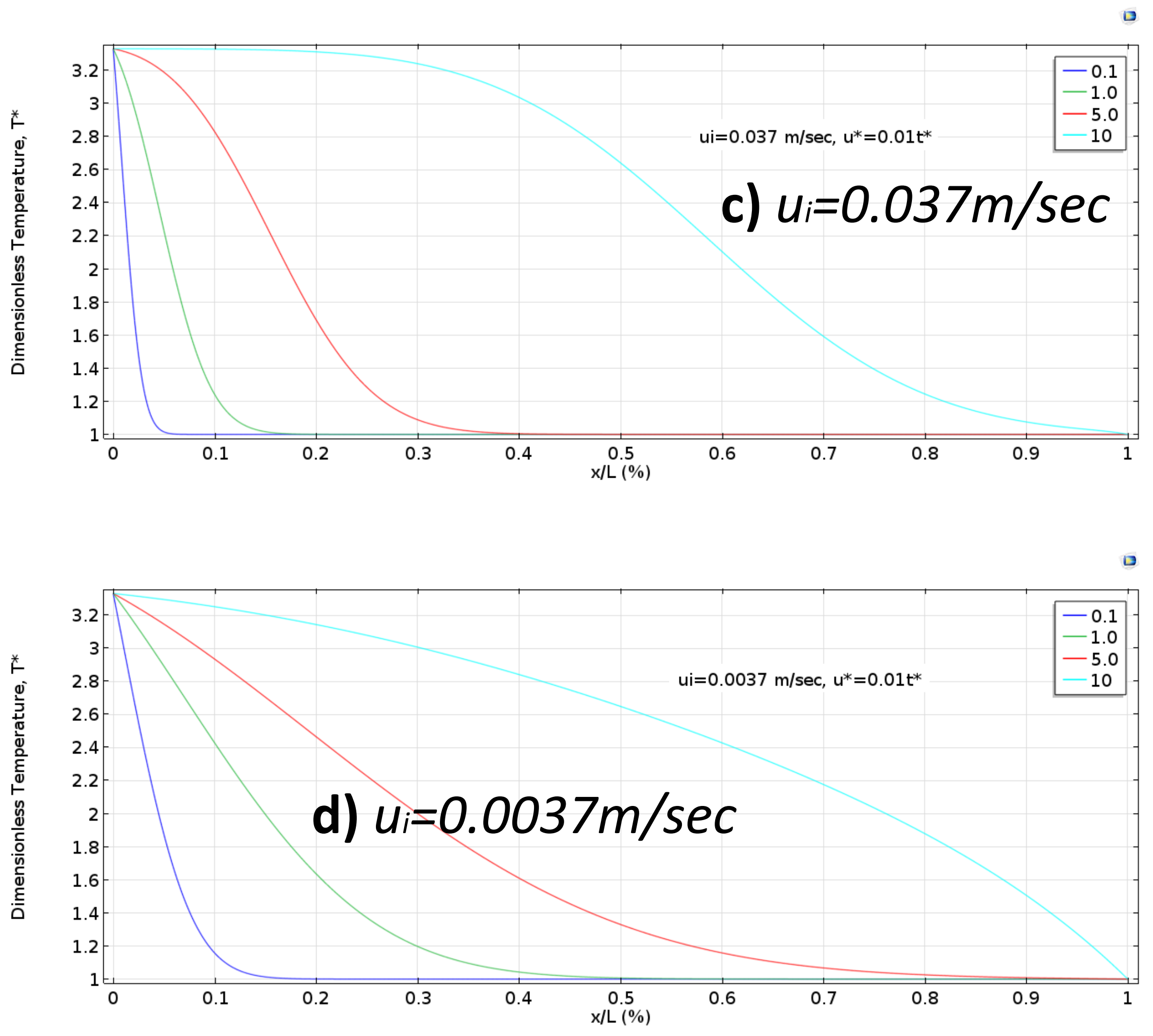

Figure 4. Dimensionless temperature versus Dimensionless distance at two different initial velocities c, d

CONCLUSIONS: Conduction plays the main role in heat propagation inside oil reservoir while convection has less impact on the process. However, time and steam velocity are the main parameters that control the process.

REFERENCES:

1. Lake, L.W., Johns, R. T., Rossen, W. R., and Pope, G. A., Fundamentals of enhanced oil recovery, pages 375-377, Society of Petroleum Engineers SPE, Texas, USA (2014)