C1PoC-04: Numerical studies on the effects of hot end temperature on a single-stage multi-bypass type pulse tube cryocooler

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1. Introduction

➢Single-stage pulse tube cryocooler is widely used in many fields because of its high efficiency, low vibrations and compactness.

➢Our laboratory is committed to the development and application of single-stage pulse tube cryocoolers. The inertance tube, gas reservoir and double-inlet are used as phase adjusting mechanism in the single-stage multi-bypass type pulse tube cryocoolers (SMPTCs).

➢ At present, the lowest refrigeration temperature is 13.9 K and about 400 mW of refrigerating capacity was achieved at 20 K with 250 W of electrical input. This generation of pulse tube cryocoolers have been applied in many applications such as materials science, optical measurement and mechanical measurement.

➢Researches on the effects of hot end temperature on the performance of SMPTCs are of great necessary to make sure the SMPTC works at the best state..

2.Cryocooler description

➢The schematic of the SMPTC is shown in Figure.1, when the SMPTC is working, the bypass orifice will be fixed at an appropriate opening, and the opening of double-inlet orifice will be regulated continuously to make sure the SMPTC working with an optimum performance.

➢For a certain SMPTC, the opening of bypass orifice (D_b) is significant to the overall performance since it is inconvenient to adjust when made.

➢This research will analysis the effects of hot end temperature (T_h) on the performance of SMPTC with needle valve of the double-inlet orifice closed.

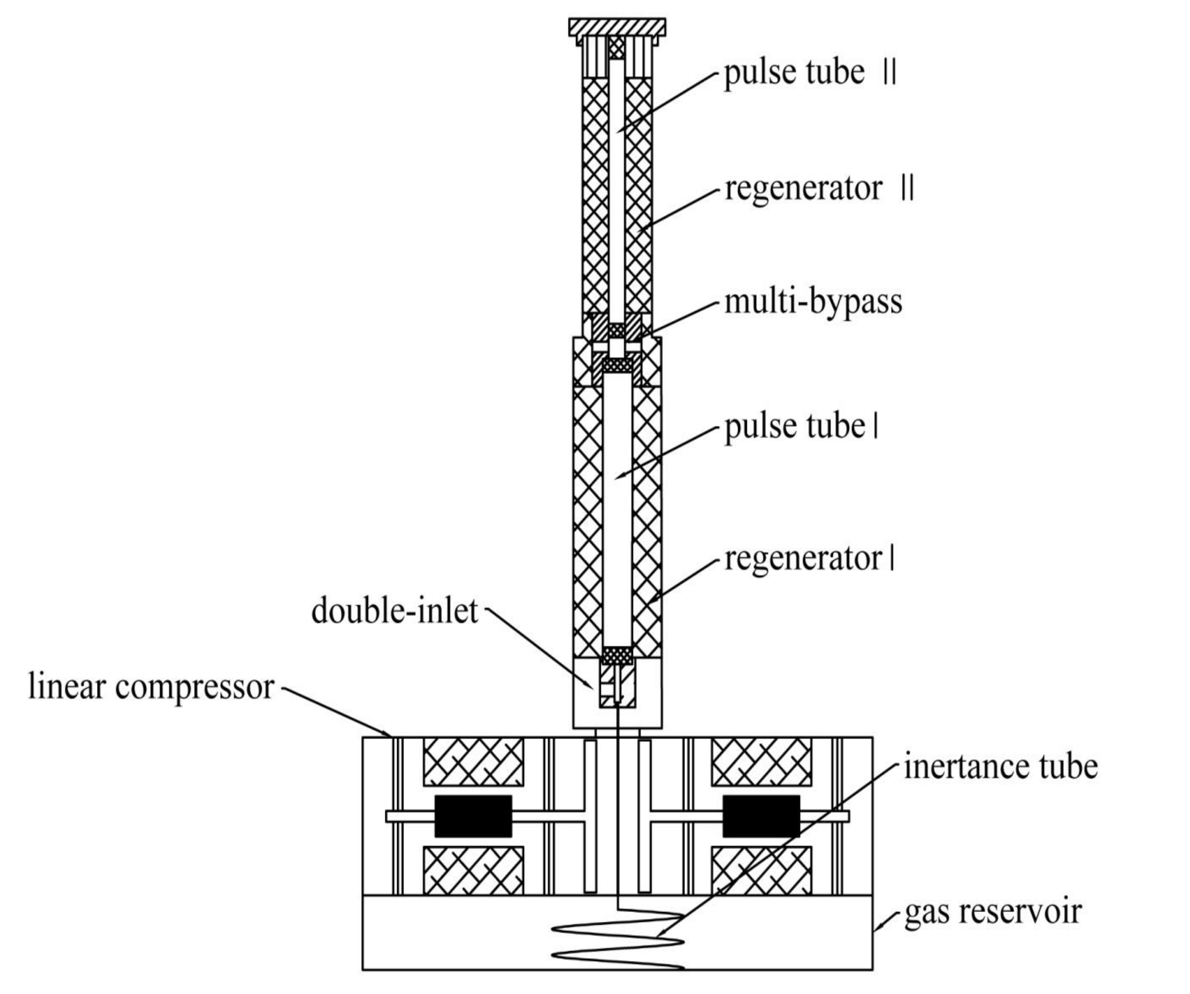

Figure 1. Schematic of the SMPTC.

Acknowledgements

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3. Numerical results and discussion

Numerical simulation was completed with the software Sage. The operating frequency and filling pressure are 30Hz and 2.2 MPa respectively in the numerical simulation. Temperature of compressor, hot end heat exchanger, inertance tubes and gas reservoir are set to be equal to the hot end temperature (T_h). Temperature of cold head (T_c) and bypass position (T_b) are taken into account with output PV power of compressor kept at certain value.

➢ Figure 2 shows the relationship among D_b, T_c and T_b of SMPTC developed in our laboratory, an optimum opening of bypass orifice is found to achieve a best performance.

➢ T_c decreases from 34.7 K to 25.9 K and then increases to 31.9 K when D_b changes from 0.2 mm to 1.2 mm, while T_b decreases from 163.0 K to 95.0 K monotonously. The optimum opening of bypass orifice is 0.75 mm when T_h is 280 K and PV is 180 W.

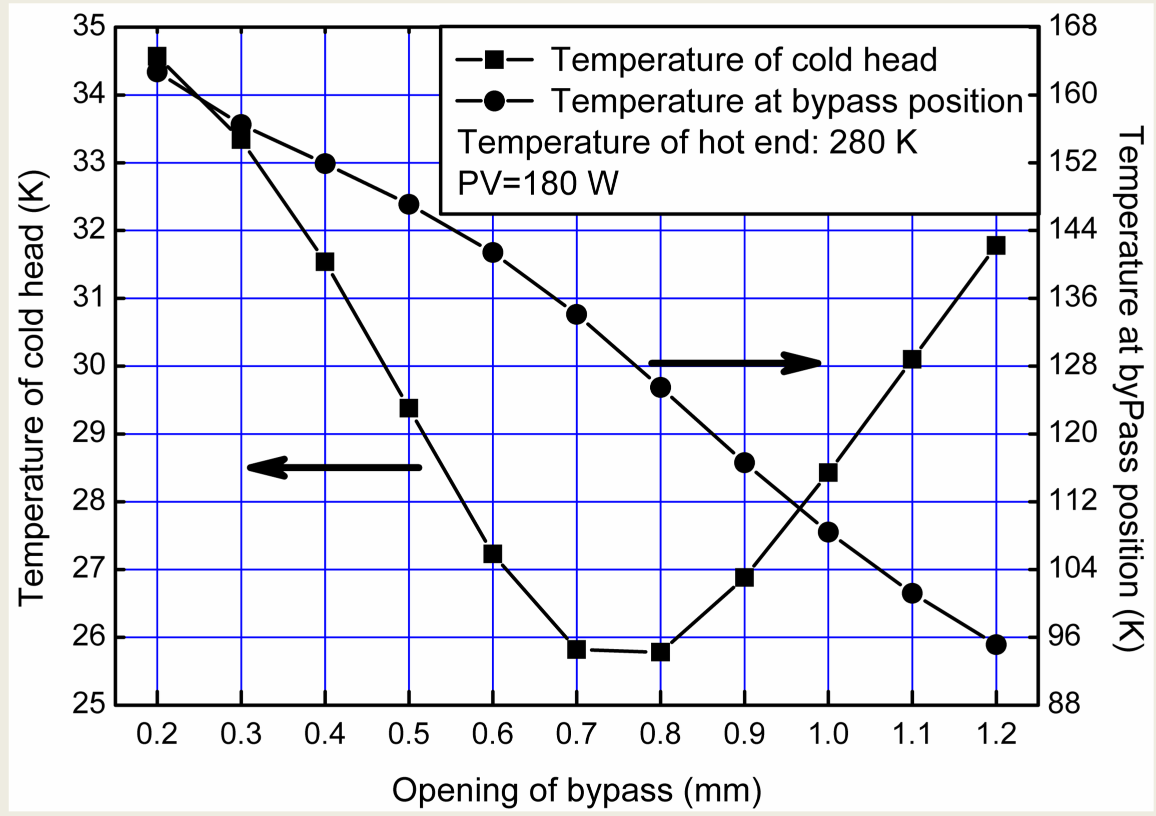

Figure 2. Influence of opening of bypass orifice.

➢ To make sure the SMPTC operates with a best performance, the value of D_b should be the optimum one when other geometry and operating parameters are invariable.

➢ The SMPTCs should have an optimal opening of bypass orifice of 0.75 mm when the ambient temperature is about 280 K.

➢ For SMPTCs working on conditions ambient temperature lower or higher than 280 K, 0.75 mm may not be the optimum opening. The optimum values of D_b for each T_h between 240 K and 320 K are provided in figure 3. It is obvious that a higher T_h corresponds to a smaller optimal opening of bypass orifice in this temperature range.

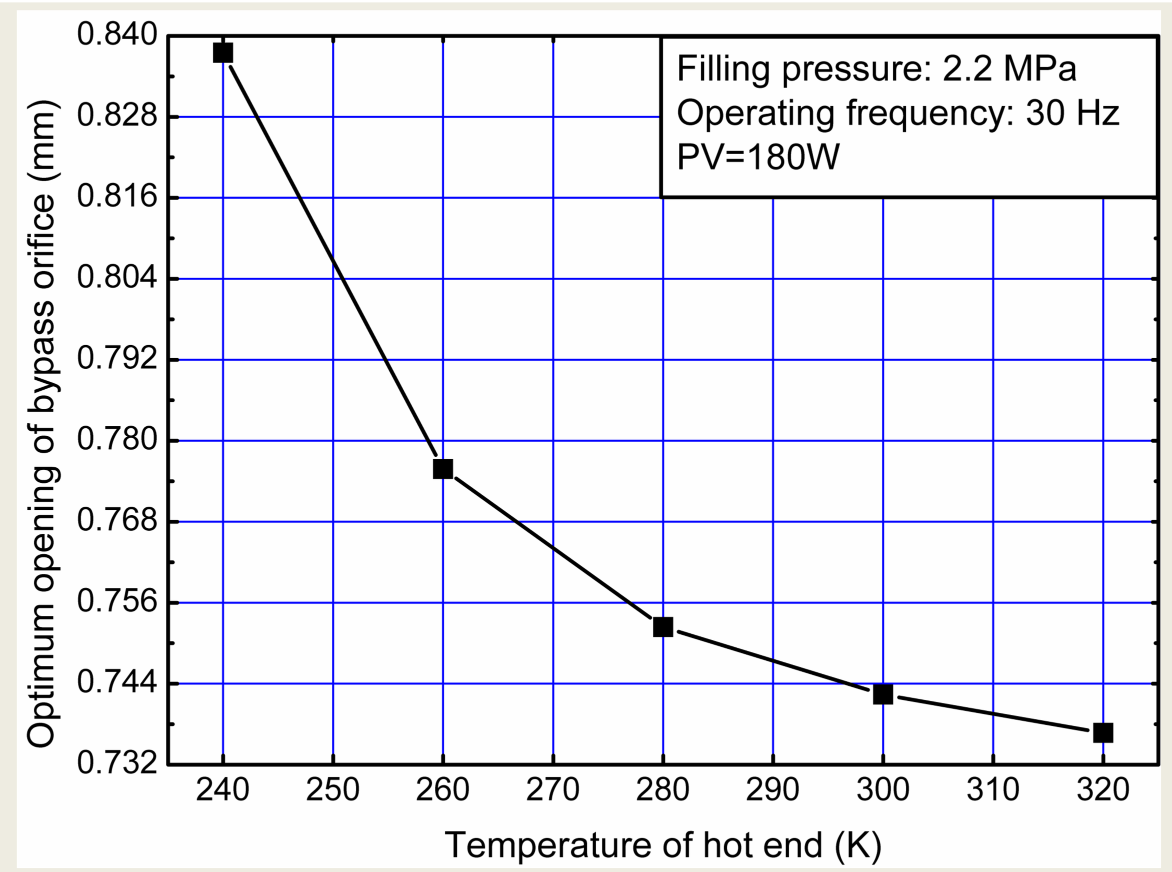

Figure 3. Influence of hot end temperature on the optimum value of D_b.

➢ Figure 4 shows the influence of T_h on the performance of SMPTC when D_b is optimal at each point of T_h.

➢ For every T_h, when PV power is set always to be 180 W and D_b is set to be optimal, both T_c and T_b increase with T_h changing from 240 K to 320 K with an increment of 14.6 K and 42 K respectively.

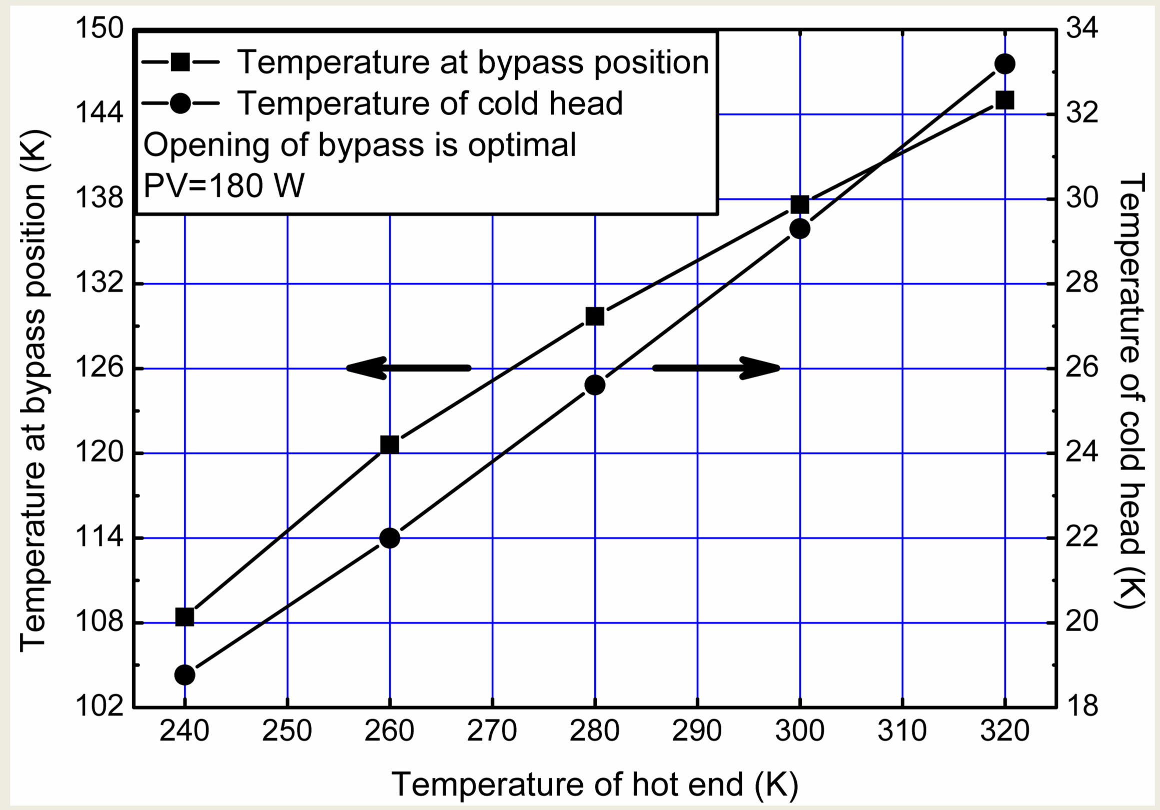

Figure 4. Influence of hot end temperature on the performance of SMPTC (D_b is optimal for each T_h).

➢ Actually, the opening of bypass orifice is inconvenient to adjust since the bypass orifice is inside of the regenerator.

➢ Figure 5 shows the influence of T_h on T_c when D_b is kept at constant 0.5 mm, 0.7 mm and 0.9 mm respectively, and T_c corresponding to each T_h with D_b optimized is shown in this figure too.

➢ For certain working condition, any value of D_b diffident to an optimal one will lead to a poor performance of a SMPTC, and no value can be optimal in all conditions. However, some values of D_b acquiring a performance approach to a best one on most occasions is a best choice for the SMPTCs. For example, 0.7 mm would be a commendable choice for this kind of SMPTCs when T_h changes between 240 K and 320 K. For some applications when T_h can be lower than 240 K at most time, 0.9 mm would be appropriate for D_b although it will get poor performance when working at room temperature.

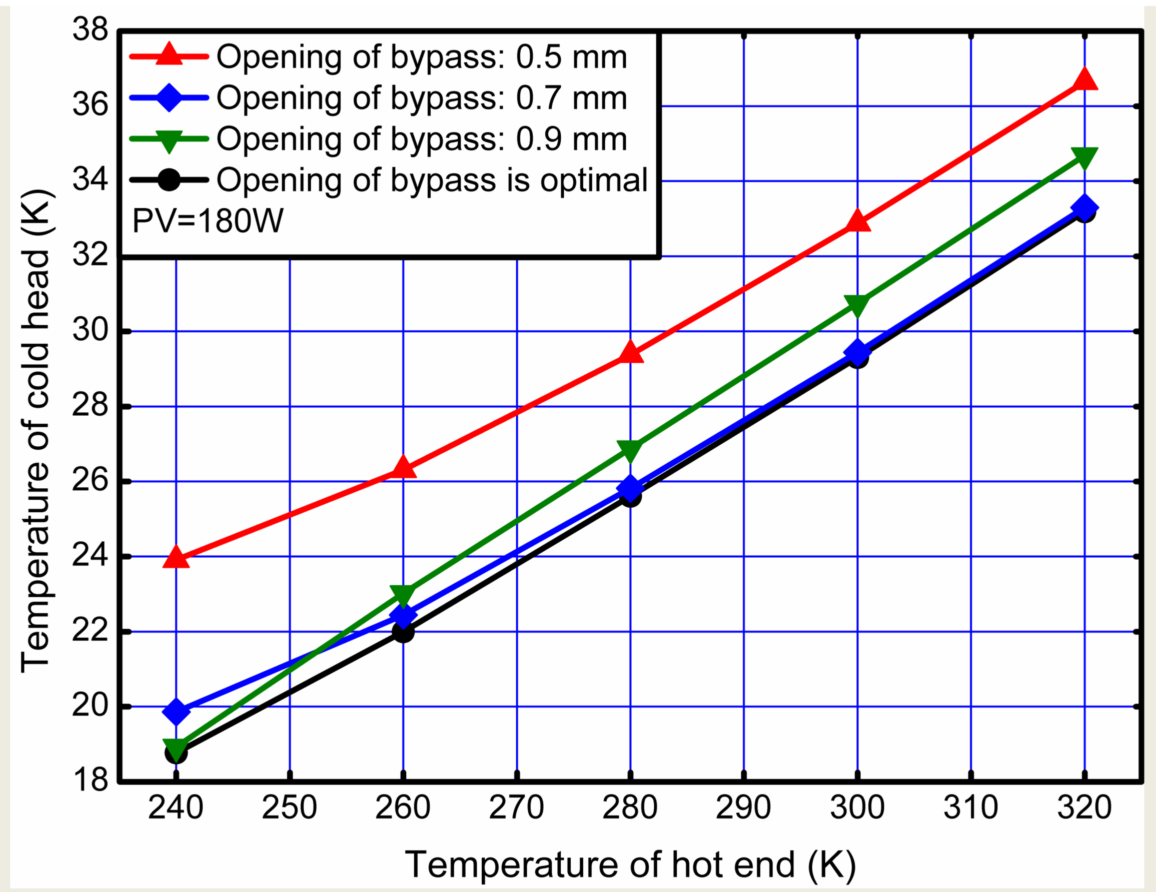

Figure 5. Influence of T_h on the performance of SMPTC (D_b = 0.5 mm, 0.7 mm, 0.9 mm and optimum)

➢ The multi-bypass orifice plays an important role in dividing gas flow in the regenerator into two streams, of which one gets into the middle of pulse tube (the mass flow rate is defined as $\dot{m}_b$), and the other into the second regenerator (the mass flow rate is defined as $\dot{m}_r$).

➢ When $\dot{m}_b$ and $\dot{m}_r$ are replaced by amplitudes respectively, the percentage m defined as $m = \dot{m}_b/(\dot{m}_b + \dot{m}_r)$ reflects the distribution capacity of multi-bypass orifice.

➢ Figure 6 shows the influence of T_h on the percentage m with different opening of multi-bypass orifice. The SMPTCs will attain a best performance when m is between 12% and 13.5%. However. For a certain opening of multi-bypass orifice, the percentage m will increase with T_h changing from 240 K to 320 K.

➢ A higher T_h would lead to a higher average temperature of helium in the regenerator II, which would produce larger flow resistance in regenerator II.

➢ When T_h increased, the mass flow rate through multi-bypass orifice will increase because of the increase of flow resistance in regenerator II. For this reason, the percentage m will increase with T_h when PV power and D_b are both constant.

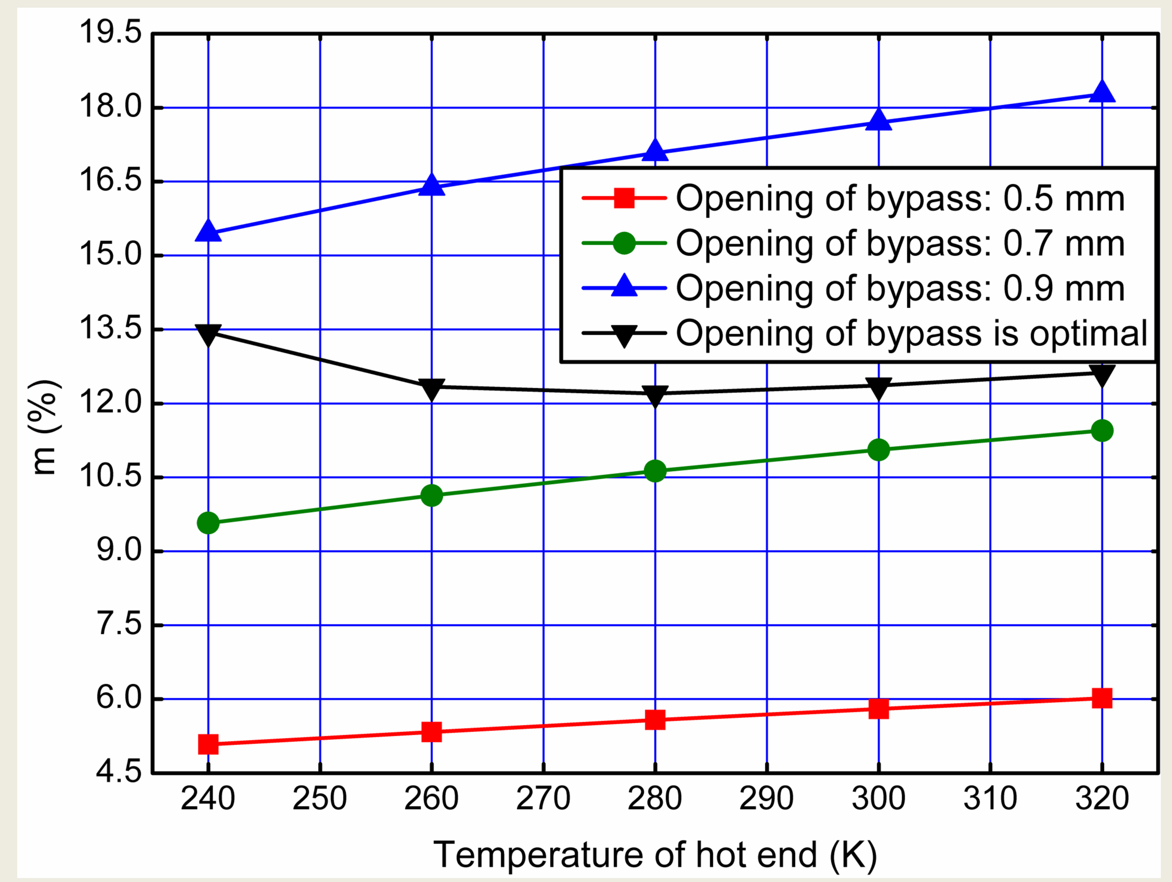

Figure 6. Influence of hot end temperature on m.

4. Conclusions

➢ Numerical studies on the influence of hot end temperature on performances of SMPTCs have been conducted with software Sage. The changes of T_h have great influence on the temperature distribution and mass flow rate distribution inside of SMPTCs.

➢ When the double-inlet orifice is closed and PV power are kept the same value, the lowest temperature achieved would have at least 14.6 K of difference with the temperature of hot end changing in the range of 240 K to 320 K.

➢ T_h affects the optimal value of D_b, and a negative correlation was found in the relationship between T_h and optimal value of D_b. The opening of bypass orifice should be given according to the temperature of operating environment.