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Full Length Research Paper

Effects of mass flow rate in terms of pressure drop and heat transfer characteristics

Masoud Asadi[1] and Dr Ramin Haghighi Khoshkhoo[2]

[1]Department of Mechanical Engineering, Azad Islamic University Science and Research branch, Tehran, Iran,
[2]Department of Mechanical Engineering and Energy engineering, Power and Water University of Technology, Tehran, Iran

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This study present a study on pressure drop and mass flow rate based on changing mass flow rate in a plate-fin heat exchanger with Wavy fin. Thermo-hydraulic design of compact heat exchangers is strongly dependent upon the mass flow rate value. It has direct impact on pressure drop , Reynolds number ,convective coefficient , overall heat transfer coefficient and heat exchanger efficiency. Hence, optimal mass flow rate, is one of the key notes to design a heat exchanger. As we expected, both pressure drop and convective coefficient increase with growing mass flow rate. However, the optimal mass flow rate is also strongly dependent on the heat exchanger dimensions.

Keywords: Mass flow rate, Plate-fin heat exchanger, Wavy fin

INTRODUCTION

Compact heat exchanger are widely used in aerospace , automobile and cryogenic industries because of their compactness for desired thermal performance, which resulting in reduced space, weight, support structure, footprint, energy requirement and cost. Depending on the application, various types of augmented heat transfer surfaces such as wavy fins, louvered fins, strip fins, plain fins and pin fins are used. There is, of course, an associated increase in the pressure drop due to increased friction and form drag contribution from the finite thickness of the interrupted fins (Sheikh et al., 2010). The surface geometries of wavy fins are described by the fin height (h), transverse spacing (s) and thickness (t). (Figure 1)

Thermo-hydraulic design of a compact heat exchanger is strongly dependent upon the mass flow rate. Consequently, the performance of heat transfer surfaces in terms of Colburn factor j and friction factor f as well as Reynolds number changing with increasing or decreasing mass flow rate directly. We focus here on wavy fin (11.5-3/8 W, 11.44-3/8 W, 17.8-3/8 W). The heat exchanger performance vs mass flow rate is presented and discussed. As we will see, having increased mass flow rate for both hot and cold stream, pressure drop and convective coefficient will rise. On the other hands, total annul costs also will increase. Hence, finding a optimal mass flow rate in order to have the highest heat exchanger efficiency and the lowest annual costs is so important for a fix equipment engineer.

Review of experimental results concerning convective heat transfer in microchannels was presented by Morini (Morini, 2007). Additional review results were obtained for the friction factor, the laminar-to-turbulent transition, and the Nusselt number in channels having hydraulic

*Corresponding Author E-mail: masoud2471@gmail.com

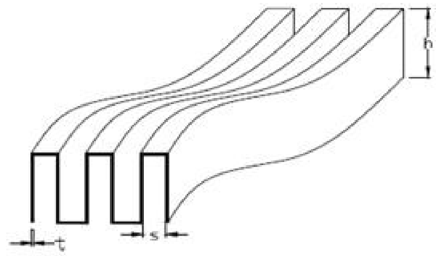

Figure 1. Wavy fin schematic

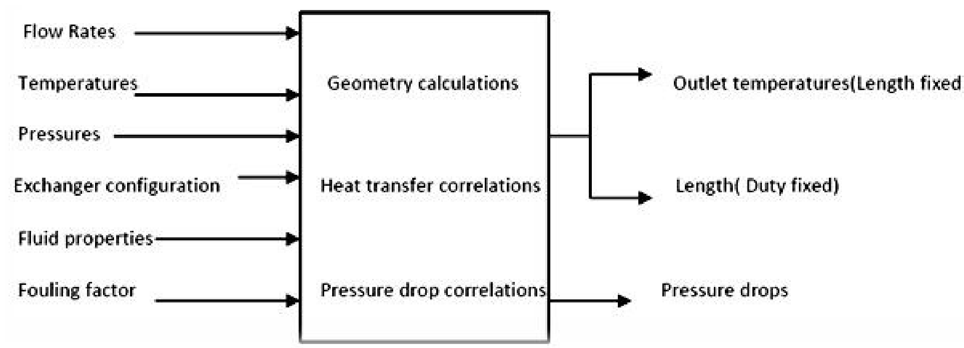

Figure 2. Rating program

diameters less than 1 mm. Pen and Peterson (Peng and Peterson, 1996) studied the convective heat transfer and flow friction for water flow in micro channel structures. Martin (Martin, 1992) studied the heat transfer and pressure drop characteristics of plate heat exchangers.

Theoretical analysis

Any discussion of the design process for heat exchanger must be based on a clear understanding of the criteria by which the heat exchanger will be judged .criterion is that a heat exchanger should satisfy is the fulfillment of the process requirements: to accomplish the thermal change on the streams within the allowable pressure drops, and to retain the capability to do this in the presence of fouling until the next scheduled maintenance period (HEDH, 1983; Incropera et al, 2010; Kays and London, 1984; Xie et al., 2008).

There is a distinction to be made among the terms selection, rating and design of a compact heat exchanger. Though often used interchangeably, these terms refer to quite different aspects of the heat exchanger specification problems and its solutions.

Rating is the computational process by which one determines the thermal performance and pressure drops if two specified streams are introduced into an essentially completely defined heat exchanger (Grossberger and Procaccia, 1983). The rating procedure, taking the inlet flow rates and temperatures (Russell et al., 1980), the fluid properties and the heat exchanger parameters as input. The rating program calculates either the outlet temperatures and thermal duty or the required length of the heat exchanger to accomplish the thermal change. In either case, the rating program will also calculate the pressure drop of each stream. (Figure 2)

To calculate pressure drops we can use Equation of (1)

$$\Delta P_1 = \frac{G_1^2}{2\rho_{in,1}}\left[\left(1+K_{C,1}-\sigma_1^2\right)+2\left(\frac{\rho_{in,1}}{\rho_{out,1}}-1\right)+\left(f_1\times\frac{S_1}{A_1}\times\frac{\rho_{in,1}}{\rho_{m,1}}\right)-\left(1-\sigma_1^2-k_{e,1}\right)\times\frac{\rho_{in,1}}{\rho_{out,1}}\right] \quad (1)$$

The terms of Eq. (1) are entrance losses, flow acceleration losses, core friction, and exit losses respectively. The K_C and K_e values depend on the cross-sectional flow geometry, σ and Reynolds number (HEDH, 1983; Kern, 1950). Noticeably, the entrance and exit losses are normally less than 10% of the total core loss (Kennedy and Eberhart, 1995; Qinghai, Provide year; Vivionacoccomariani et al., 2012). (Figure 3)

Convective coefficient is introduced by Nusselt number,

$$Nu = \frac{h.D_h}{k}$$

Where D_h and k are hydraulic diameter and thermal conductivity. So, convective coefficient can be calculated by,

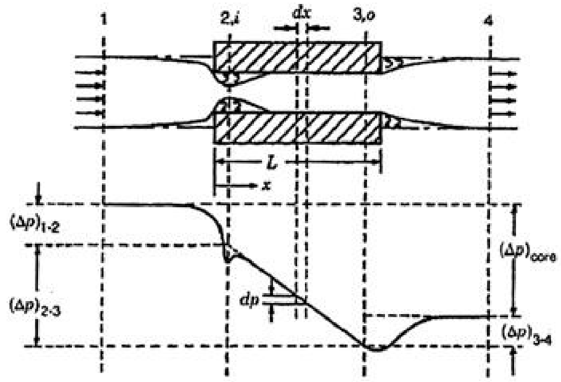

Figure 3. Pressure drop terms

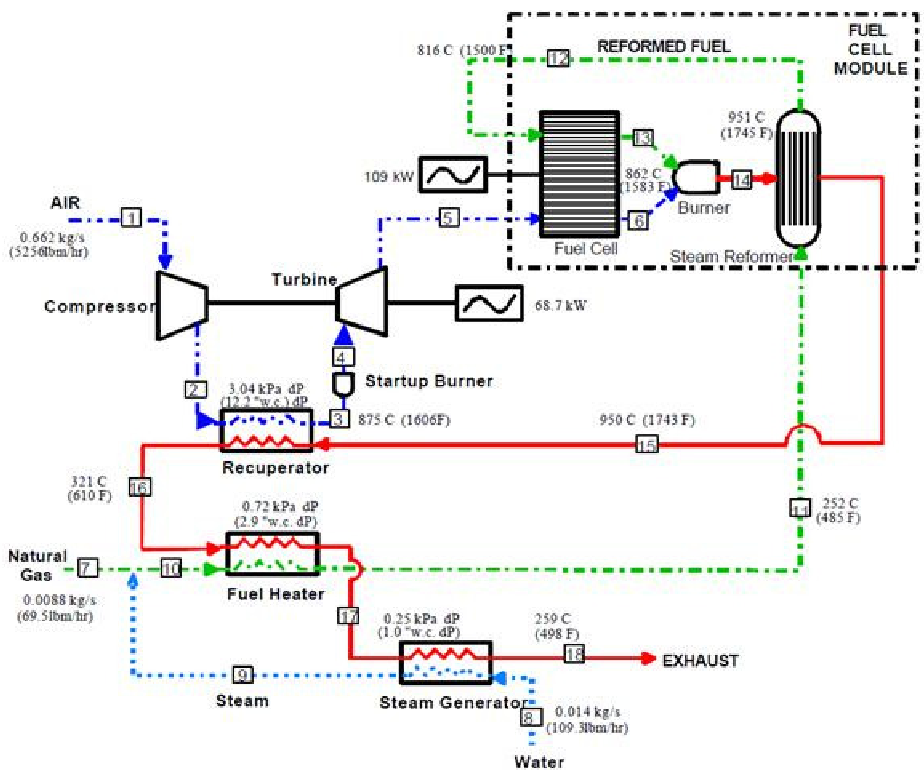

Figure 4. Microturbine cycle (180kw) (Larry et al., 1999)

Table 1. Fluid properties(For microturbine 180 kw) (Larry et al., 1999)

State Point	Flow(kg/s)	Temperature(C)	Pressure(kPa)	Enthalpy(J/kg)
1	0.662	15	101.3	-1.35e5
2	0.662	178	304	3.11e4
3	0.662	875	304	8.05e5
4	0.662	875	304	8.05e5
5	0.662	642	106.9	5.35e5
6	0.123	862	106.8	7.83e5
7	0.009	15	204.8	-4.74e6
8	0.014	25	120	-1.60e7
9	0.014	108	120	-1.33e7
10	0.023	93	120	-9.95e6

Table 1. Continue

11	0.023	252	120	-9.95e6
12	0.023	816	120	-3.16e6
13	0.036	862	120	-7.57e6
14	0.685	951	106.8	1.33e4
15	0.685	950	106.8	3.19e4
16	0.685	321	106.8	-7.17e5
17	0.685	309	106.8	-7.30e5
18	0.685	259	106.8	-7.86e5

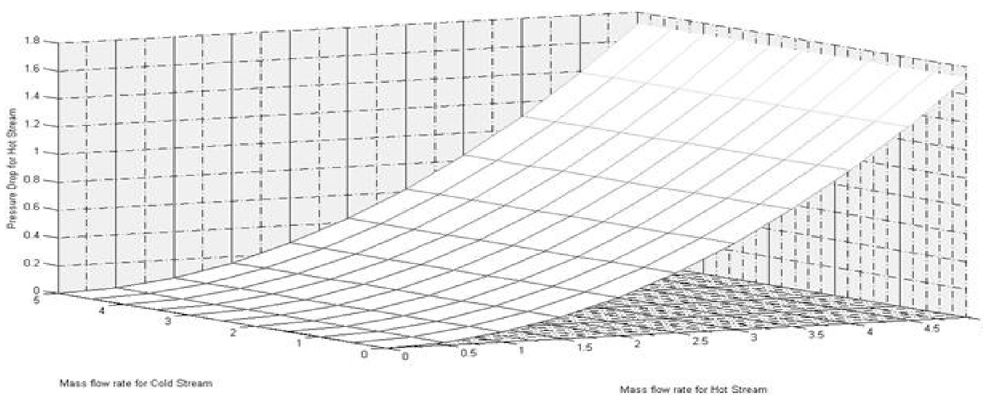

Figure 5. Pressure drop for hot stream versus mass flow rate

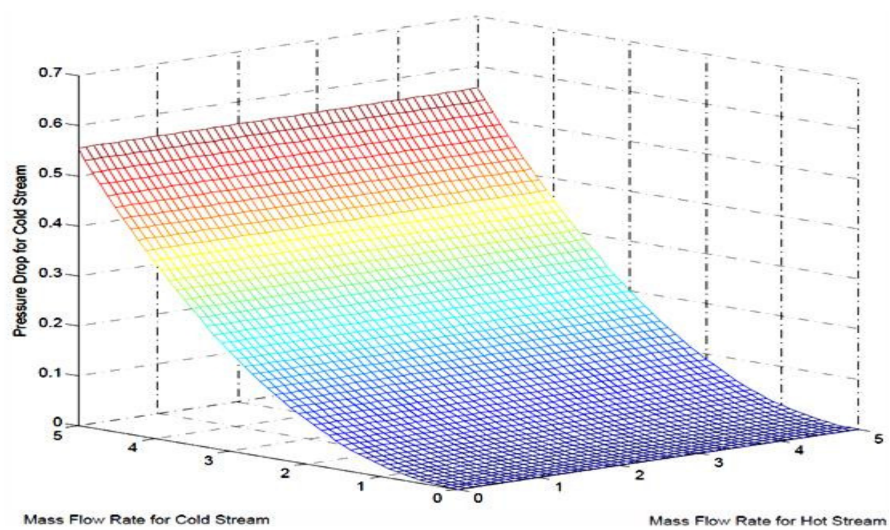

Figure 6. Pressure drop for cold stream versus mass flow rate

$$h = j.G.C_p.\Pr^{\frac{-2}{3}}$$

Here, heat transfer coefficient is calculated from j, colburn factor.

Experimental set-up and operating conditions

For the test section, plate-fin heat exchanger with different types of wavy fins is employed in a microturbine cycle. Here, the role of plate-fin heat exchanger is pre-heating inlet air from exhaust gases. (Figure 4) (Table 1)

RESULT AND DISCUSSION

The wavy fin with “11.5-3/8 W” feature is used in microtu-

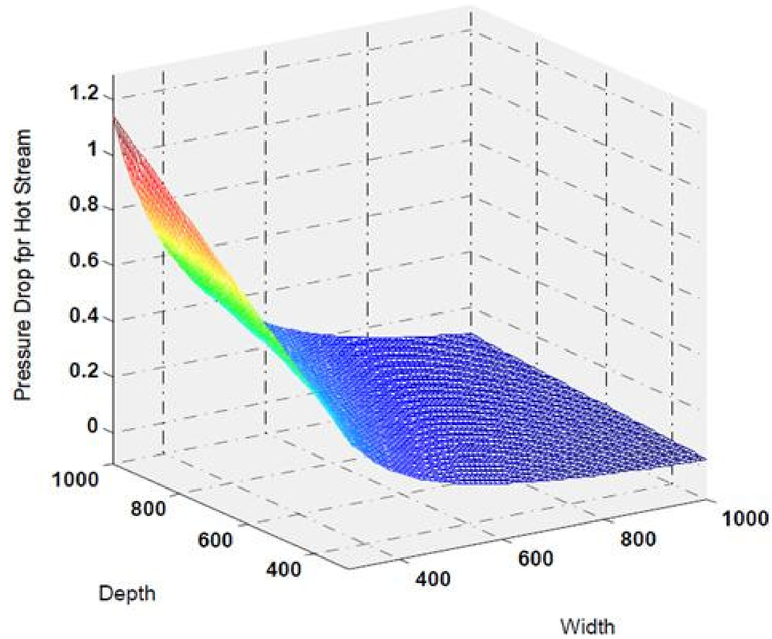

Figure 7. Pressure drop for cold stream versus width and depth of the heat exchanger

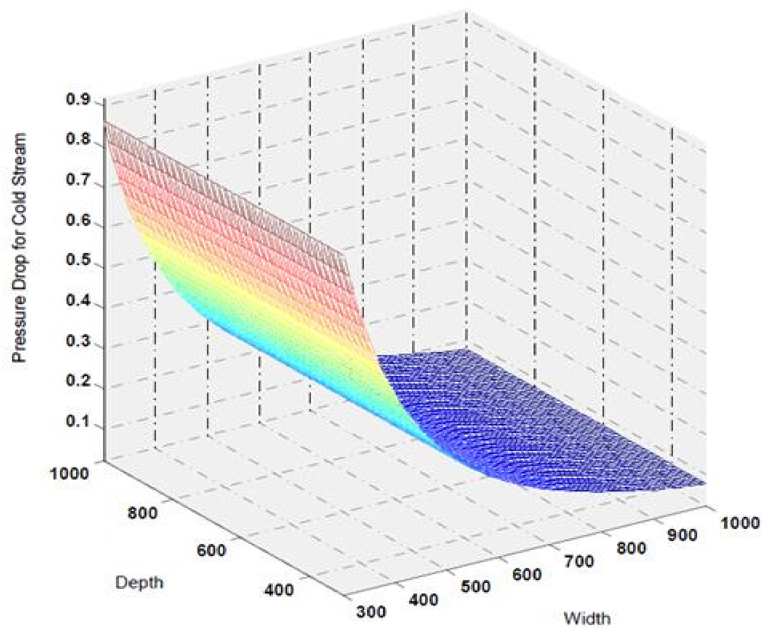

Figure 8. Pressure drop for cold stream versus width and depth of the heat exchanger

rbine cycle. Here, diagrams of changing pressure drops for inlet air and outlet gases are: (Figure 5 and 6)

As it is clear in these figures, pressure drop increases with rising mass flow rate either for hot and cold stream. However, fin of "11.5-3/8 W" shows different behavior for hot and cold stream. The main reasons for this refer to hydraulic diameter and outlet gas properties. Here, it is assumed that mechanical design process has been completely done, and width, depth and the numbers of fins are determined. To study mass flow rate effects, having optimal width and depth is so important. Here, an Algorithm is written for showing effects of the width and depth of heat exchanger on terms of pressure drop. (Figure 7)

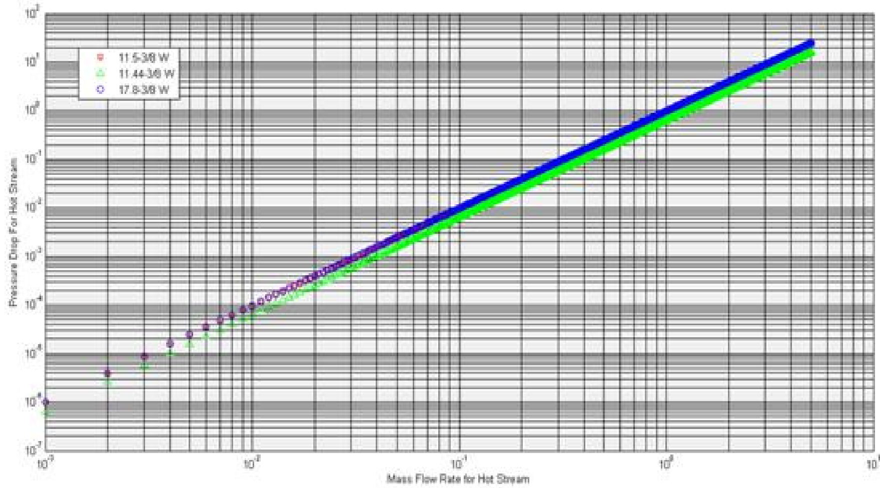

Figure 9. Pressure drop for different wavy fins in hot side

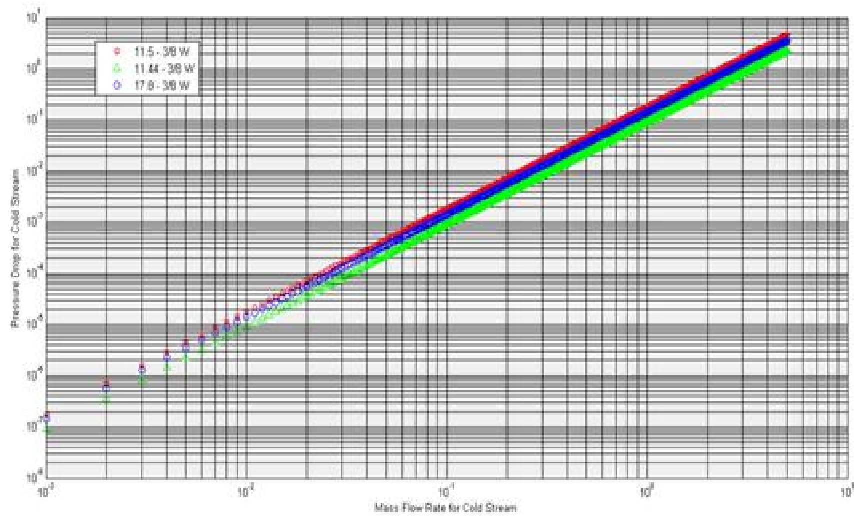

Figure 10. Pressure drop for different wavy fins in cold side

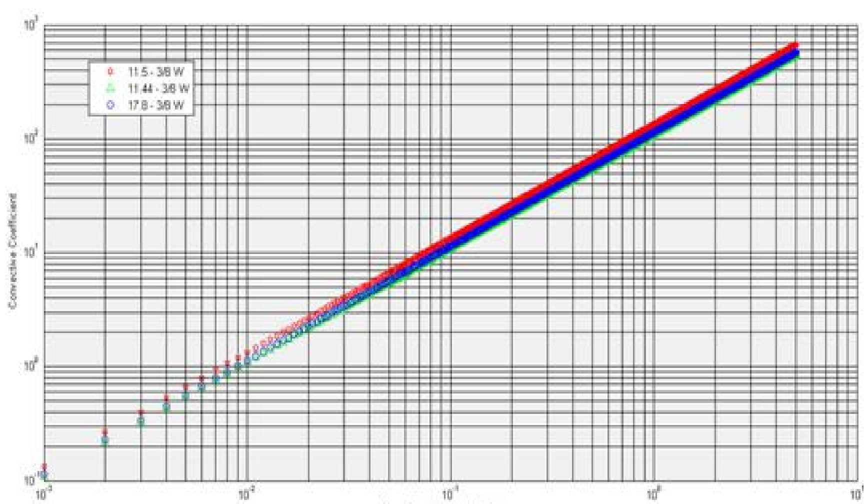

Figure 11. Convective coefficient for different wavy fins in hot side

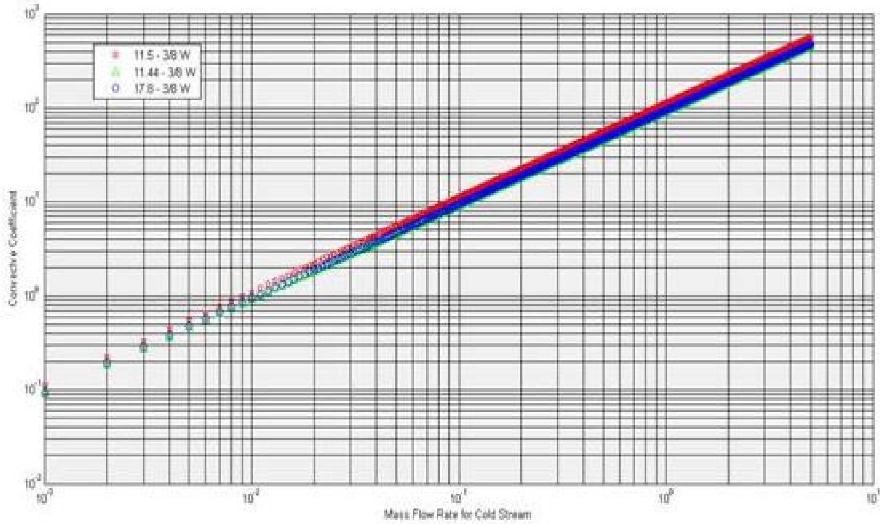

Figure 12. Convective coefficient for different wavy fins in cold side

In these figures, the width of the heat exchanger plays a key role. When it is small (Between 400 to 600 mm) pressure drop has the largest value. Although, having increased depth, pressure drop will climb up, but when width is small the depth of the heat exchanger has not any influence on cold stream pressure drop. When the width is between 700 to 1000 mm both graphs have the same trend. However, the important note is that, here, the depth of the heat exchanger is not very important and can have any value. Of course, we prefer that it be high, because heat transfer area is more. (Figure 8, 9, 10 and 11)

In addition, the effects of mass flow rate on convective coefficient are shown in Figure. (10) and (11). As we expecting, convective coefficient will rise with growing mass floe rate like pressure drop. Consequently, the optimal mass flow rate must be selected based on these diagrams and total annual costs chart as well.

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