热力系统设计与实践第一次作业

Question

对于一个具有再热的两级回热理想循环（抽气压力分别为$0.8\,MPa$和$0.2\,MPa$），蒸汽发生器出口新蒸汽压力$4\,MPa$，干度0.9975；绝热膨胀后排出，排气压力为新蒸汽压力的30%，经蒸汽再热到190℃；低压缸绝热膨胀，乏汽冷凝压力$4\,kPa$。不考虑泵做功。

假定新蒸汽总流量为1kg/s；用于再热的新蒸汽流量为β，两级回热的抽汽流量分别为$\alpha 1$和$\alpha 2$，给水温度为T_{fw}，高压缸排气压力为P_a。

1. 用于再热的新蒸汽和高压缸排气直接混合进行再热，推导循环热效率表达式，并计算循环热效率；（3分）
2. 假设再热器再热蒸汽之前，对湿蒸气进行汽水分离，分离效率100%，推导循环热效率表达式，并计算循环热效率；（4分）
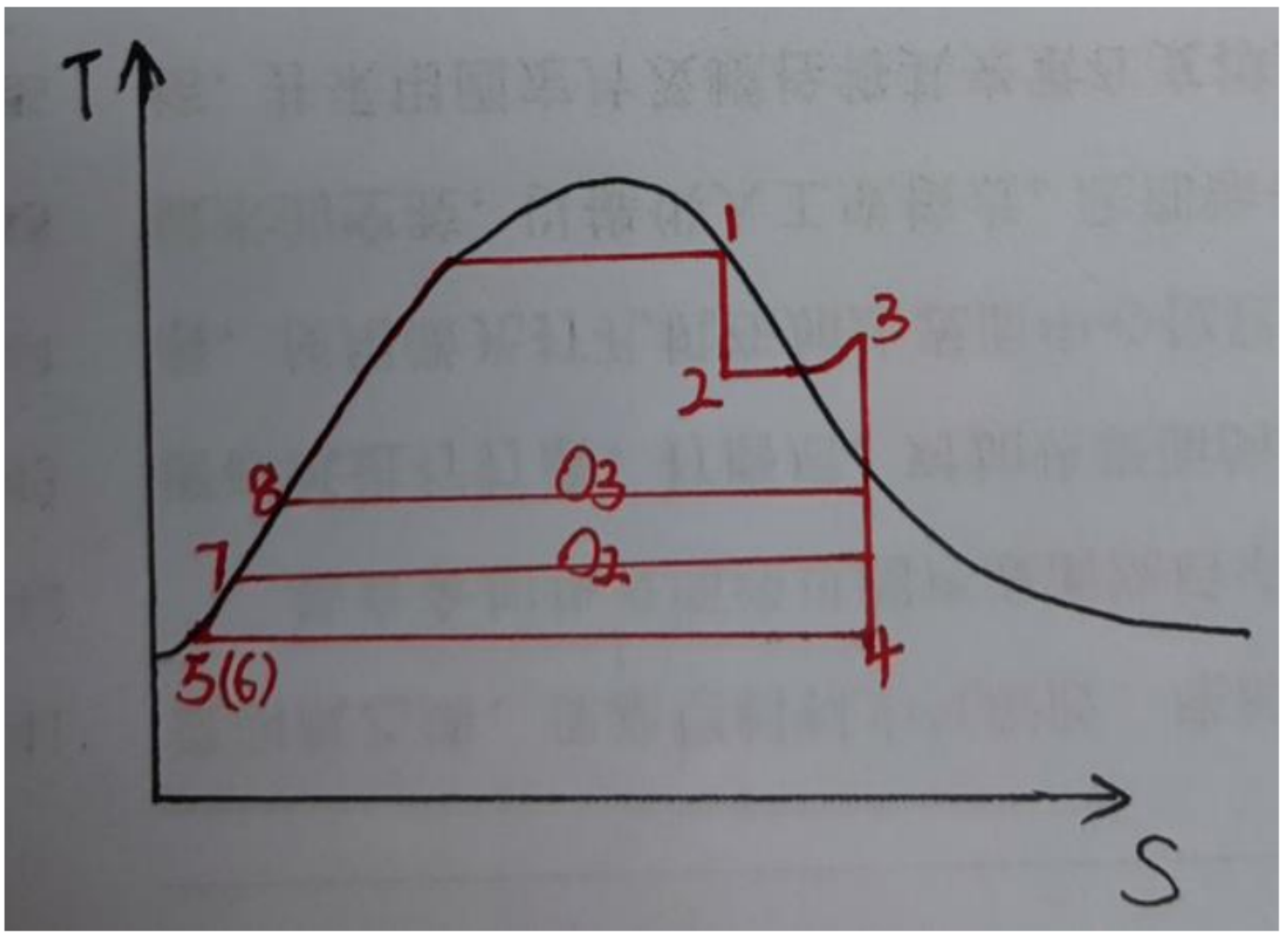3. 改变抽气压力，分析抽气压力对循环热效率影响。（3分）

Answer

1) 用于再热的新蒸汽和高压缸排气直接混合进行再热，推导循环热效率表达式，并计算循环热效率

热力系统如图：
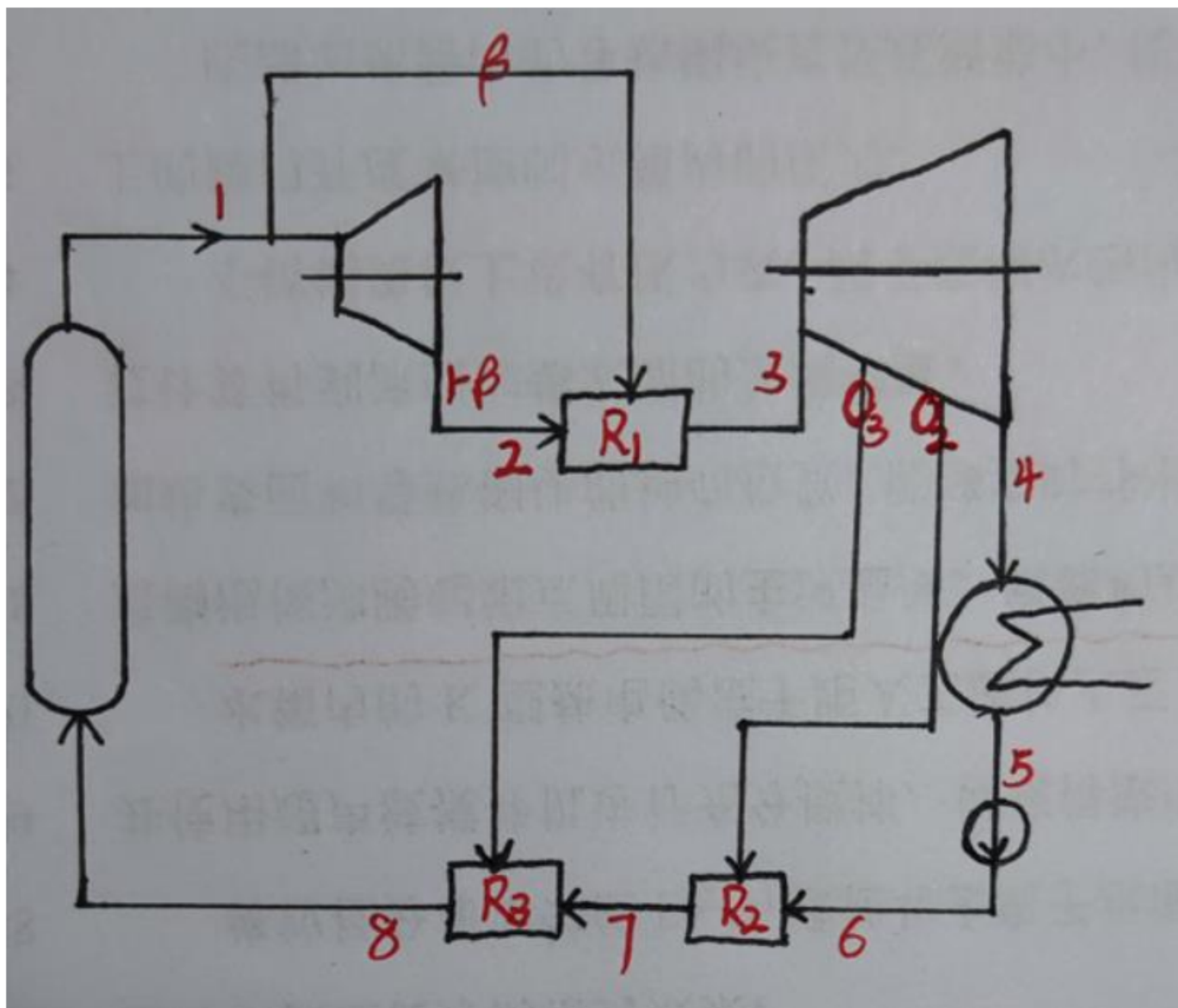
循环表示为：

循环热效率可以表示为：

$$w_t = \frac{w_{net}}{q_1} = 1 - \frac{q_2}{q_1}$$
$$q_1 = h_1 - h_8$$
$$q_2 = (1 - \alpha_1 - \alpha_2)(h_4 - h_5)$$

h_1，h_4，h_5，h_8可以通过查表得到，α_1, α_2可以通过回热器的能量平衡方程计算。

对于回热器$R2$，有

$$(1 - \alpha_1 - \alpha_2)h_6 + \alpha_2 h_{o_2} = (1 - \alpha_1)h_7$$
$$\alpha_2 = \frac{(1 - \alpha_1)(h_7 - h_6)}{h_{o_2} - h_6}$$

对于回热器$R3$，有

$$(1 - \alpha_1)h_7 + \alpha_1 h_{o_3} = h_8$$
$$\alpha_1 = \frac{h_8 - h_7}{h_{o_3} - h_7}$$

参数	单位	计算公式或来源	计算数值
h_1	kJ/kg	由P,x查表	2796.61

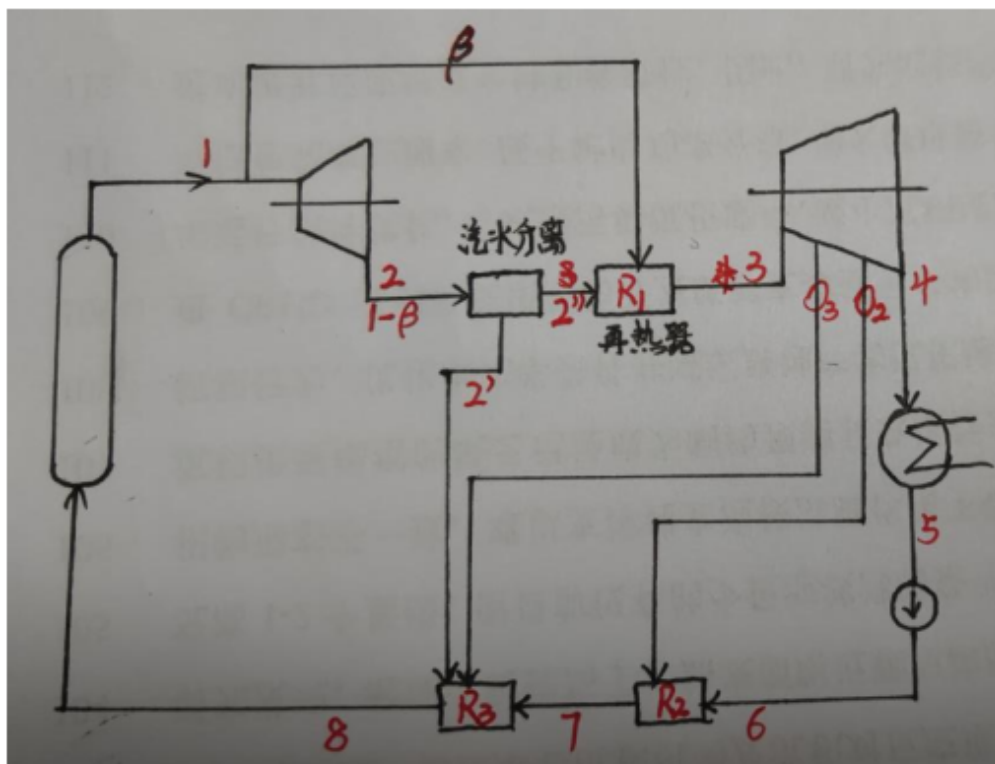| 参数	单位	计算公式或来源	计算数值
h_4	kJ/kg	由P,s查表	1967.77
h_5	kJ/kg	由P,x查表	121.40
h_6	kJ/kg	由P,x查表	121.40
h_7	kJ/kg	由P,x查表	504.68
h_8	kJ/kg	由P,x查表	721.02
h_{o_2}	kJ/kg	由P,s查表	2473.03
h_{o_3}	kJ/kg	由P,s查表	2711.73
α_1	%	$\alpha_1 = \frac{h_8-h_7}{h_{o_3}-h_7}$	9.8
α_2	%	$\alpha_2 = \frac{(1-\alpha_1)(h_7-h_6)}{h_{o_2}-h_6}$	14.7

由此可得：

$$q_1 = h_1 - h_8 = 2796.61 - 721.02 = 2075.59 kJ/kg$$
$$q_2 = (1 - \alpha_1 - \alpha_2)(h_4 - h_5) = (1 - 0.098 - 0.147) \times (1967.77 - 121.40) = 1394.01 kJ/kg$$
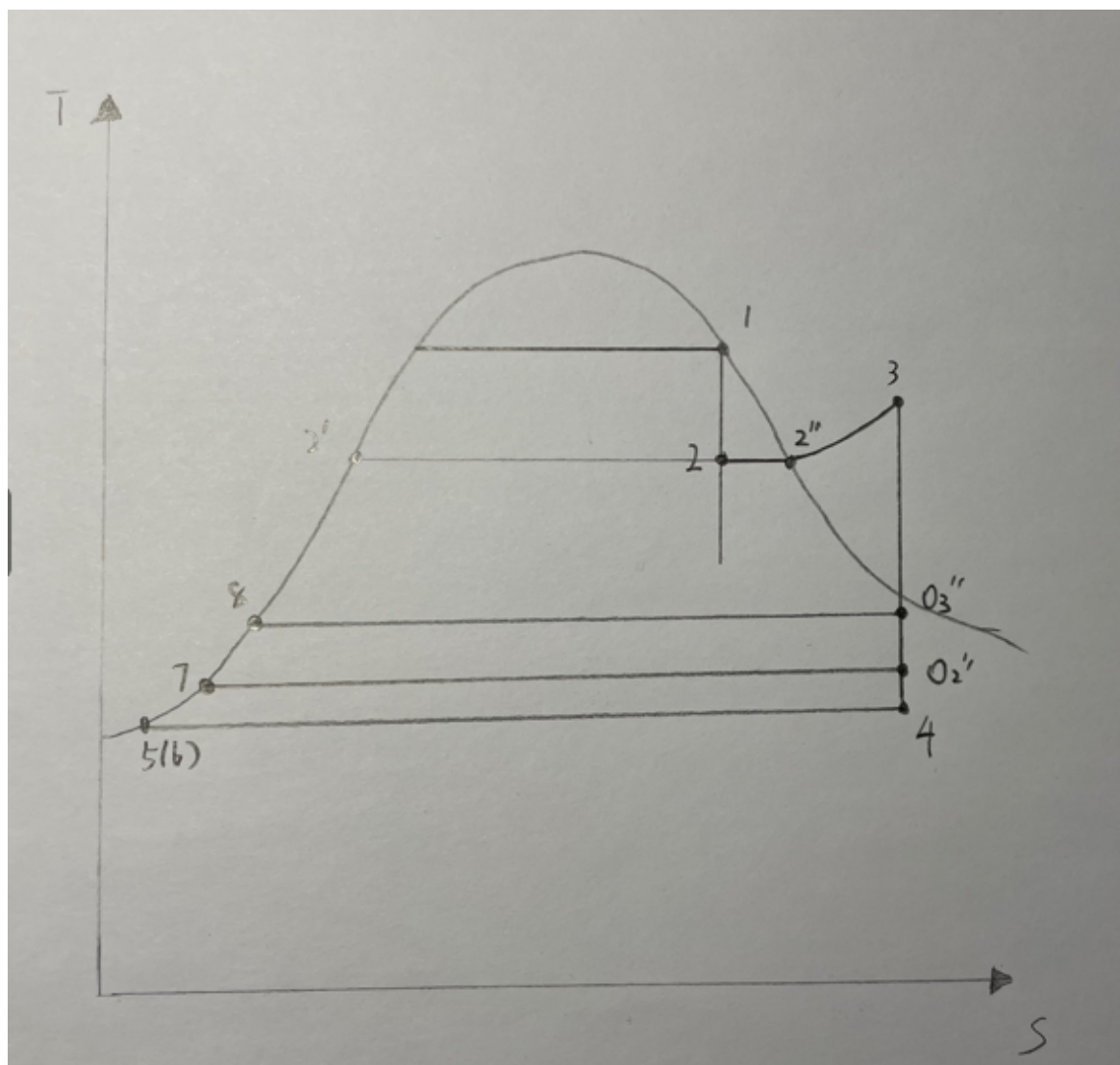
即

$$w_t = \frac{w_{net}}{q_1} = 1 - \frac{q_2}{q_1} = 32.84\%$$

2) 假设再热器再热蒸汽之前，对湿蒸气进行汽水分离，分离效率100%，推导循环热效率表达式，并计算循环热效率

热力系统如图：

循环表示为：

根据能量守恒列平衡方程

对于换热器有：

$$x_2(1-\beta)h_{2''} + \beta h_1 = (x_2 + \beta - \beta x)h_3$$
$$\beta = \frac{xh_{2''} - xh_3}{h_3 - h_3x - h_1 + xh_{2''}}$$

对于回热器$R2$，有

$$(x_2 + \beta - \beta x - \alpha_1 - \alpha_2)h_6 + \alpha_2 h_{o_2} = (x_2 + \beta - \beta x - \alpha_1)h_7$$
$$\alpha_2 = \frac{(x_2 + \beta - \beta x - \alpha_1)h_6 - (x_2 + \beta - \beta x - \alpha_1)h_7}{h_6 - h_{o_2}}$$

对于回热器$R3$，有

$$(x_2 + \beta - \beta x - \alpha_1)h_7 + \alpha_1 h_{o_3} + (1-\beta)(1-x)h_{2'} = h_8$$
$$\alpha_1 = \frac{(x + \beta - \beta x)h_7 + (1-\beta)(1-x)h_{2'} - h_8}{h_7 - h_{o_3}}$$

参数	单位	计算公式或来源	计算数值
x	$-$	由P, s查表	0.8950
h_1	kJ/kg	由P, x查表	2796.61
$h_{2'}$	kJ/kg	由P, x查表	798.50
$h_{2''}$	kJ/kg	由P, x查表	2783.77
h_4	kJ/kg	由P, s查表	1967.77
h_5	kJ/kg	由P, x查表	121.40
h_6	kJ/kg	由P, x查表	121.40
h_7	kJ/kg	由P, x查表	504.68
h_8	kJ/kg	由P, x查表	721.02
h_{o_2}	kJ/kg	由P, s查表	2473.03
h_{o_3}	kJ/kg	由P, s查表	2711.73
β	$\%$	$\beta = \frac{xh_{2''} - xh_3}{h_3 - h_3x - h_1 + xh_{2''}}$	41.52
α_1	$\%$	$\alpha_1 = \frac{(x+\beta-\beta x)h_7 + (1-\beta)(1-x)h_{2'} - h_8}{h_7 - h_{o_3}}$	8.98
α_2	$\%$	$\alpha_2 = \frac{(x_2+\beta-\beta x-\alpha_1)h_6 - (x_2+\beta-\beta x-\alpha_1)h_7}{h_6 - h_{o_2}}$	13.83

由此可得：

$$q_1 = h_1 - h_8 = 2075.59 kJ/kg$$
$$q_2 = [1 - (1-\beta) \times (1-x) - \alpha_1 - \alpha_2](h_4 - h_5) = 1311.69 kJ/kg$$

即

$$w_t = \frac{w_{net}}{q_1} = 1 - \frac{q_2}{q_1} = 36.80\%$$

3) 改变抽气压力，分析抽气压力对循环热效率影响

计算程序如下：

```python
from iapws import IAPWS97 as ip
import numpy as np

def get_alpha_1(p1, p2):
    x = 0.8950
    h3 = 2789.45
    h1 = 2796.61
    h2pp = 2783.77
    h2p = 798.5
    h7 = ip(P = p2, x = 0).h
    h8 = ip(P = p1, x = 0).h
    ho3 = ip(P = p1, s = 6.534).h
    beta = 0.4152
    return ((x + beta - beta*x)*h7 + (1-beta)*(1-x)*h2p - h8)/(h7 - ho3)

def get_alpha_2(a1, p1, p2):
    x = 0.8950
    h3 = 2789.45
    h1 = 2796.61
    h2pp = 2783.77
    beta = 0.4152
    h2p = 798.5
    h6 = 121.4
    h7 = ip(P = p2, x = 0).h
    h8 = ip(P = p1, x = 0).h
    ho2 = ip(P = p2, s = 6.534).h
    ho3 = ip(P = p1, s = 6.534).h
    return ((x+beta-beta*x-a1)*h6 - (x+beta-beta*x-a1)*h7)/(h6 - ho2)

def get_q_2(b, a1, a2):
    x = 0.895
    h4 = 1967.77
    h5 = 121.40
    return (1 - (1-b)*(1-x)-a1-a2)*(h4 - h5)

def get_w(q2):
    return (1 - q2/2075.59)

mat = np.empty([5,5], dtype = float)

for i in range(5):
    for j in range(5):
```

```
        m = [0.6, 0.7, 0.8, 0.9, 1.0]
        n = [0.01, 0.1, 0.2, 0.3, 0.4]
        p_01 = m[i]
        p_02 = n[j]

        b = 0.4152
        a1 = get_alpha_1(p_01, p_02)
        a2 = get_alpha_2(a1, p_01, p_02)

        q2 = get_q_2(b, a1, a2)

        w_t = get_w(q2)
        if i == 2 and j == 2:
            print(b, a1, a2, w_t, q2)
        mat[i][j] = w_t

    print(mat)
```

计算结果如下：

抽气压力 (MPa)	0.6	0.7	0.8	0.9	1.0
0.01	0.34866411	0.35423918	0.35222027	0.34982848	0.3474607
0.1	0.35609172	0.36232593	0.36065282	0.35851569	0.35635875
0.2	0.36263428	0.36942122	0.36803946	0.366117	0.36413778
0.3	0.36849501	0.3757552	0.37462404	0.37288635	0.37106014
0.4	0.37381368	0.38148563	0.38057354	0.3789975	0.37730517

Appendix

物性查找图形程序如下：

```
import sys
from PyQt5.QtWidgets import QApplication, QWidget, QLabel, QLineEdit, QPushButton,
QVBoxLayout, QHBoxLayout
import iapws

class SteamCalculator(QWidget):
    def __init__(self):
        super().__init__()

        # 初始化界面
        self.initUI()
```

```python
    def initUI(self):
        # 标签和输入框
        self.lbl_inputs = QLabel("请输入以下两个参数")
        self.lbl_param1 = QLabel("压强(P)(MPa)")
        self.le_param1 = QLineEdit()
        self.lbl_param3 = QLabel("温度(T)(℃)")
        self.le_param3 = QLineEdit()
        self.lbl_param4 = QLabel("焓(h)(kJ/kg)")
        self.le_param4 = QLineEdit()
        self.lbl_param5 = QLabel("熵(s)(kJ/(kg*K))")
        self.le_param5 = QLineEdit()
        self.lbl_param6 = QLabel("干度(x) - ")
        self.le_param6 = QLineEdit()

        # 按钮
        self.btn_calculate = QPushButton("计算")
        self.btn_calculate.clicked.connect(self.calculate)

        # 结果标签
        self.lbl_outputs = QLabel("计算结果: ")

        # 布局
        vbox_inputs = QVBoxLayout()
        vbox_inputs.addWidget(self.lbl_inputs)
        hbox_param1 = QHBoxLayout()
        hbox_param1.addWidget(self.lbl_param1)
        hbox_param1.addWidget(self.le_param1)
        vbox_inputs.addLayout(hbox_param1)
        hbox_param3 = QHBoxLayout()
        hbox_param3.addWidget(self.lbl_param3)
        hbox_param3.addWidget(self.le_param3)
        vbox_inputs.addLayout(hbox_param3)
        hbox_param4 = QHBoxLayout()
        hbox_param4.addWidget(self.lbl_param4)
        hbox_param4.addWidget(self.le_param4)
        vbox_inputs.addLayout(hbox_param4)
        hbox_param5 = QHBoxLayout()
        hbox_param5.addWidget(self.lbl_param5)
        hbox_param5.addWidget(self.le_param5)
        vbox_inputs.addLayout(hbox_param5)
        hbox_param6 = QHBoxLayout()
        hbox_param6.addWidget(self.lbl_param6)
        hbox_param6.addWidget(self.le_param6)
        vbox_inputs.addLayout(hbox_param6)
        vbox_inputs.addWidget(self.btn_calculate)
        vbox_outputs = QVBoxLayout()
        vbox_outputs.addWidget(self.lbl_outputs)

        hbox = QHBoxLayout()
        hbox.addLayout(vbox_inputs)
        hbox.addLayout(vbox_outputs)

        self.setLayout(hbox)

        # 设置窗口
        self.setGeometry(400, 400, 600, 250)
        self.setWindowTitle('水蒸气物性参数计算器')
```

```python
        self.show()

    def calculate(self):
        # 获取用户输入的参数
        param1 = self.le_param1.text()
        # param2 = self.le_param2.text()
        param3 = self.le_param3.text()
        param4 = self.le_param4.text()
        param5 = self.le_param5.text()
        param6 = self.le_param6.text()

        # 确定已知参数的数量
        known_params = [p for p in [param1, param3, param4, param5, param6] if p]
        num_known_params = len(known_params)

        # 检查已知参数数量是否为2
        if num_known_params != 2:
            self.lbl_outputs.setText("请输入两个已知参数")
            return

        # 判断用户输入的已知参数是哪两个，并将其转换为浮点数
        if param1 and param3:
            try:
                # 可能会导致错误的代码
                p = float(param1)
                T = float(param3)+273.15
                steam = iapws.IAPWS97(P=p, T=T)
            except:
                # 处理捕获的异常
                self.lbl_outputs.setText("出错,超出输入范围")

        elif param1 and param4:
            try:
                p = float(param1)
                h = float(param4)
                steam = iapws.IAPWS97(P=p, h=h)

            except:
                # 处理捕获的异常
                self.lbl_outputs.setText("出错,超出输入范围")
        elif param1 and param5:
            try:
                p = float(param1)
                s = float(param5)
                steam = iapws.IAPWS97(P=p, s=s)

            except:
                # 处理捕获的异常
                self.lbl_outputs.setText("出错,超出输入范围")

        elif param4 and param5:
            try:
                h = float(param4)
                s = float(param5)
                steam = iapws.IAPWS97(h=h, s=s)

            except:
                # 处理捕获的异常
```

```python
                self.lbl_outputs.setText("出错,超出输入范围")

        elif param6 and param1:
            try:
                x = float(param6)
                p = float(param1)
                steam = iapws.IAPWS97(x=x, P=p)

            except:
                # 处理捕获的异常
                self.lbl_outputs.setText("出错,超出输入范围")

        elif param6 and param3:
            try:
                x = float(param6)
                T = float(param3)+273.15
                steam = iapws.IAPWS97(x=x, T=T)

            except:
                # 处理捕获的异常
                self.lbl_outputs.setText("出错,超出输入范围")

        else:
            self.lbl_outputs.setText("请输入两个有效参数")
            return

        # 显示计算结果
        try:
            # 可能会导致错误的代码
            self.lbl_outputs.setText(f"Phase = {steam.phase}\nrho = {steam.rho:.3f}
 kg/m³\nP = {steam.P:.3f} MPa\nv = {steam.v:.6f}m^3/kg\nT = {steam.T-273.15:.3f} ℃\nh
 = {steam.h:.3f} kJ/kg\ns = {steam.s:.6f} kJ/(kg*K)\nx = {steam.x:.6f}")

        except:
            # 处理捕获的异常
            self.lbl_outputs.setText("出错,请检查输入")

if __name__ == '__main__':
    app = QApplication(sys.argv)
    ex = SteamCalculator()
    sys.exit(app.exec_())
```