Documentation

Flotation plays a crucial role in the financial performance of mineral processing by influencing the relative amount of metal and gangue in a (final) concentrate. Achieving maximum profitability is the ultimate goal in this industry. Nonetheless, identifying the optimal flotation condition is not straightforward. One effective approach is to test a range of conditions in a flotation plant and plot the corresponding profit-recovery values. The plot can then be interpolated to pinpoint the ideal recovery of the plant and the ideal concentrate grade, which can be used to set the optimal condition. This program has been developed to solve this optimisation problem and calculate relevant parameters of the plant under each of the conditions.

The program requires data that consist of:

- The name of a flotation plant – any name that is not null, starts by a space, and contain any of the special characters (tab, /, \, :, *, ^, “, <, >, |).
- The price per ton of metal ($) – must be positive.
- The treatment charge per ton of concentrate ($) – must be positive.
- The flowrate of the feed to the plant (tph) – must be positive.
- The grade of the feed to the plant (tph) – must be between 0 and 100.
- The number of different conditions operated on the plant – must be at least 2 to do an interpolation and should be at least 5 for an interpolation with satisfactory accuracy.
- The recovery achieved by the plant under each different condition (%) – must be between 0 and 100.
- The grade of the concentrate produced by the plant on each different condition (%) – must be between the feed grade and 100.

Once the program starts, it asks users how they will provide data. They can do so by importing a file with the correct format or typing on the console. If the first choice is chosen, they just need to provide the name of a file without its extension (“.txt”). It has to be noted that the file must exist in the project’s folder, otherwise, it cannot be opened. A valid file must be tab-delimited (.txt) and have the following format, otherwise, it cannot be used. If the file cannot be opened or used, users will be asked the first question again.

- Your file name will be the name of your flotation plant.
- Line 1: The string "Price per ton of metal ($)" followed by a numeric value.
- Line 2: The string "Treatment charge per ton of concentrate ($)" followed by a numeric value.
- Line 3: The string "Feed flowrate (tph)" followed by a numeric value.
- Line 4: The string "Feed grade (%)" followed by a numeric value.
- Line 5: The string "Recovery (%)" followed by a series of numeric values (at least 2 values), each of which is the recovery achieved by the plant at each different condition.
- Line 6: The string " Concentrate grade (%)" followed by a series of numeric values (at least 2 values), each of which is the grade of the concentrate produced by the plant on each different condition.

If users prefer to give their data on the console, they firstly are asked to provide a valid name of a flotation plant. Then, they are asked to provide numeric data. During this stage, they can quit the program by typing “quit” and entre when any questions appear on the console.

After data are given, the program reads them as strings, converts them to numbers, and checks their validity, e.g., checks if all of them are numeric, checks if all of them are valid as defined above, and checks if the values of recovery achieved and grade of the concentrate produced by the plant on each of the conditions must be all unique and obey the grade-recovery inverse relationship that concentrate grade decreases as recovery increases. If some of the values in the imported file are invalid or incomplete, the check will stop immediately after the first invalid value is found, and users will be told the error and asked to opt for a choice to provide data again. If an invalid string input (except for “quit”) is typed on the console, users will be told the error and asked for a new input for the same question, not an entirely new set of data.

It should be kept in mind that, when the program receives a string input, it will read each character from left to right and convert numeric characters to a number until a non-numeric character is found. For example, if “9.81m s-2” is inputted, it can be converted to 9.81; in contrast, if “CuFeS2” is inputted, a number cannot be converted from it.

If all the values of inputted data are appropriate, they will be shown on the console. If they are inputted on the console, they are also written in a new .txt file that can be used for future input. The name of the file is the name of the plant followed by “_for_input.txt”.

Next, there will be two parts of the calculation.

1. Relevant parameters, listed as follows, of the plant operated on different conditions are calculated.
    - The flowrates of concentrate and (final) tailings.
    - The flowrates of metal in the feed, the concentrate, and the tailings.
    - The revenue from selling metal in the concentrate.
    - The treatment charge for selling the concentrate.
    - The profit.

    Once this part is done, the result of the calculation will be written in a .txt file whose name is the name of the plant followed by “_calculated.txt”.

2. The optimal point of the flotation is estimated. This is performed by a natural cubic spline interpolation using the values of recovery achieved and grade of the concentrate produced by the plant on each of the conditions to construct a grade-recovery curve. Then, a profit-recovery curve is interpolated using the grade-recovery spline – the profit at each of the 1001 recovery values along the grade-recovery spline is calculated. The highest profit, together with the corresponding (optimal) recovery, is picked among the 1001 values. The optimal concentrate grade at the optimal recovery is computed from the grade-recovery spline.
    - If the leftmost point of the profit-recovery curve is the optimum, it means that a lower recovery could lead to a higher profit.
    - If the rightmost point of the profit-recovery curve is the optimum, it means that a higher recovery could lead to a higher profit.
    - If the optimum is under the x-axis, it means that the mineral processing is non-profitable.
    - Otherwise, i.e., if the optimum is above the x-axis, it indicates the maximum profit.

    The result of the calculation is printed on the console. The 1001 sets of recovery, concentrate grade and profit values are also written in a .txt file whose name is the name of the plant followed by “_for_plot.txt”.

It is worth noting that, although a profit-recovery curve can be interpolated from the values of profit and recovery achieved by the plant on each of the conditions, it tends to be less reliable than the profit-recovery curve interpolated using the grade-recovery curve because the shape of the grade-recovery spline is constrained by the inverse grade-recovery relationship (see Appendix for an example).

After the program has finished the calculation, users can opt to either provide a new set of data and repeat the whole process or quit the program.

Appendix

Input by importing a file

demo.txt:

```
Price per ton of metal ($) 8900
Treatment charge per ton of concentrate ($)    1000
Feed flowrate (tph) 1000
Feed grade (%)      0.6
Recovery (%) 70     75     80     85     90     95
Grade of final concentrate (%)    27     26.5   26     25     21     5
```

Output

demo_calculated.txt:

```
Plant name    demo
Price per ton of metal ($) 8900
Treatment charge per ton of concentrate ($)    1000
Feed flowrate (tph) 1000
Feed grade (%)      0.6
Flowrate of metal in feed (tph)   6

       Condition 1  Condition 2  Condition 3  Condition 4  Condition 5  Condition 6
Recovery (%) 70     75     80     85     90     95
Flowrate of final concentrate (tph)     15.5556      16.9811      18.4615      20.4
       25.7143      114
Flowrate of metal in final concentrate (tph)   4.2    4.5    4.8    5.1    5.4    5.7
Grade of final concentrate (%)    27     26.5   26     25     21     5
Flowrate of tailings (tph) 984.444      983.019      981.538      979.6  974.286
       886
Flowrate of metal in tailings (tph)     1.8    1.5    1.2    0.9    0.6    0.3
Grade of tailings (%)      0.182844      0.152591      0.122257      0.0918742
       0.0615836    0.03386
Revenue from selling metal ($/hr) 37380  40050  42720  45390  48060  50730
Treatment charge ($/hr)    15555.6      16981.1      18461.5      20400  25714.3
       114000
Profit ($/hr) 21824.4      23068.9      24258.5      24990  22345.7      -63270
```

demo_for_plot.txt (only first five sets of values are shown here):

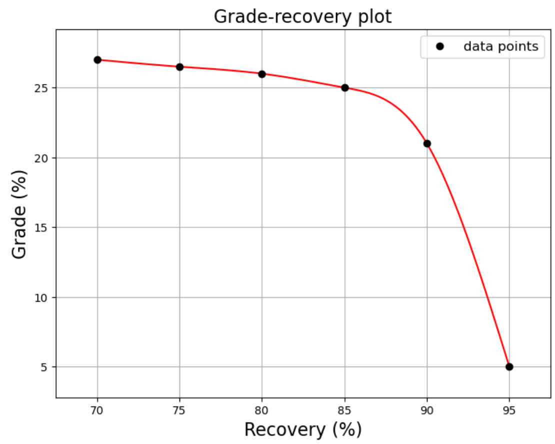
```
Recovery (%)  Concentrate grade (%)      Profit ($/hr)
70     27     21824.4
70.025 26.9973      21830.7
70.05  26.9946      21836.9
70.075 26.992 21843.2
70.1   26.9893      21849.4
```

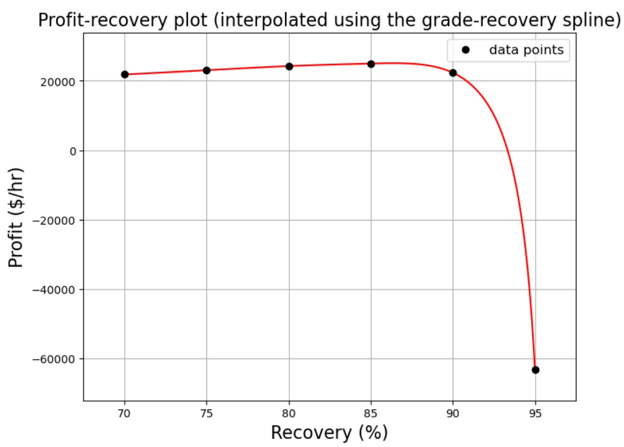
On the console:

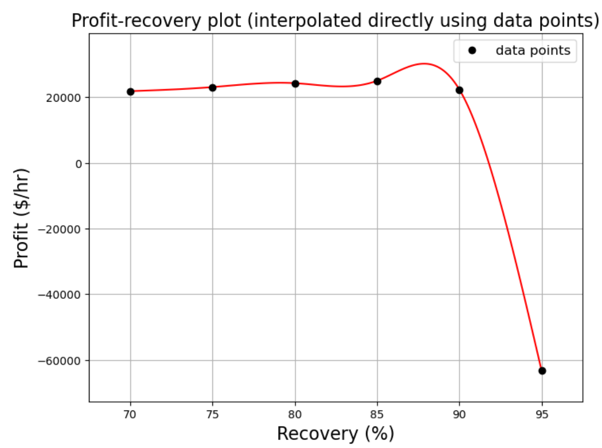
```
Your data:
Price per ton of metal ($)      8900
Treatment charge per ton of concentrate ($)     1000
Feed flowrate (tph)     1000
Feed grade (%)  0.6
Recovery (%)    70      75      80      85      90      95
Grade of final concentrate (%)  27      26.5    26      25      21      5

By a natural cubic spline interpolation, the highest profit is $25.1k per hour,
achieved at a recovery of 86.4% and a grade of 24.6%.
```

Aside: plotting the following curve in Python:

- The grade-recovery spline.
- The profit-recovery curve interpolated using the grade-recovery spline.
- The profit-recovery curve interpolated directly from the values of profit and recovery achieved by the plant on each of the conditions.







The shape of the former profit-recovery curve is constrained by the inverse grade-recovery relationship, whereas there is no constraint imposed on the interpolation using the values of profit and recovery achieved by the plant on each of the conditions directly. Therefore, the former plot tends to be more accurate and is chosen to find the optimum.

Input on the console

```
Welcome to our program for the financial optimisation of flotation.

Would you like to import your data as a file, otherwise you will need to type your data on console?
(y/n):

Plant name: flotation

Please input your data. If you would like to quit the program, you can type 'quit' and enter.

Price per ton of metal ($): 8900
Treatment charge per ton of concentrate ($): 500
Feed flowrate (tph) = 1000
Feed grade (%) = 0.6
The number of conditions: 5
Condition 1:
Recovery (%) = 90
Grade of final concentrate (%) = 15
Condition 2:
Recovery (%) = 50
Grade of final concentrate (%) = 30
Condition 3:
Recovery (%) = 70
Grade of final concentrate (%) = 27
Condition 4:
Recovery (%) = 80
Grade of final concentrate (%) = 23
Condition 5:
Recovery (%) = 60
Grade of final concentrate (%) = 29
```

Output

flotation_for_input.txt:

```
Price per ton of metal ($) 8900
Treatment charge per ton of concentrate ($)    500
Feed flowrate (tph) 1000
Feed grade (%)      0.6
Recovery (%) 50     60     70     80     90
Concentrate grade (%)      30     29     27     23     15
```

flotation_calculated.txt:

```
Plant name   flotation
Price per ton of metal ($) 8900
Treatment charge per ton of concentrate ($)    500
Feed flowrate (tph) 1000
Feed grade (%)      0.6
Flowrate of metal in feed (tph)   6

       Condition 1   Condition 2   Condition 3   Condition 4   Condition 5
Recovery (%) 50     60     70     80     90
Concentrate flowrate (tph) 10     12.4138       15.5556       20.8696       36
Flowrate of metal in concentrate (tph)  3      3.6    4.2    4.8    5.4
Concentrate grade (%)      30     29     27     23     15
Tailings flowrate (tph)    990    987.586       984.444       979.13 964
Flowrate of metal in tailings (tph)     3      2.4    1.8    1.2    0.6
Tailings grade (%)  0.30303      0.243017      0.182844      0.122558      0.0622407
Revenue from selling metal ($/hr) 26700  32040  37380  42720  48060
Treatment charge ($/hr)    5000   6206.9 7777.78       10434.8       18000
Profit ($/hr) 21700  25833.1      29602.2      32285.2      30060
```

flotation_for_plot.txt (only first five sets of values are shown here):

```
Recovery (%) Concentrate grade (%)      Profit ($/hr)
50     30     21700
50.04  29.9968      21716.8
50.08  29.9936      21733.6
50.12  29.9904      21750.5
50.16  29.9871      21767.3
```

On the console:

```
Your data:
Price per ton of metal ($)      8900
Treatment charge per ton of concentrate ($)     500
Feed flowrate (tph)     1000
Feed grade (%)  0.6
Recovery (%)    50      60      70      80      90
Concentrate grade (%)   30      29      27      23      15

By a natural cubic spline interpolation, the highest profit is $32.4k per hour,
achieved at a recovery of 82.4% and a grade of 21.4%.
```