# Optimization of Single Screw Extrusion

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- The problem to solve
- Optimization methods
- Evolutionary algorithms
- Multi-objective evolutionary algorithms
- Results

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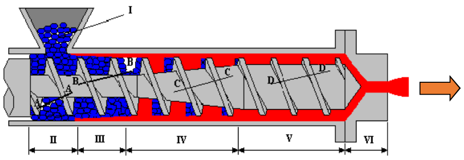
## *the problem to solve*

### Extrusion modelling

**INPUT DATA:**
- Geometry
- Polymer Properties
- Operating Conditions



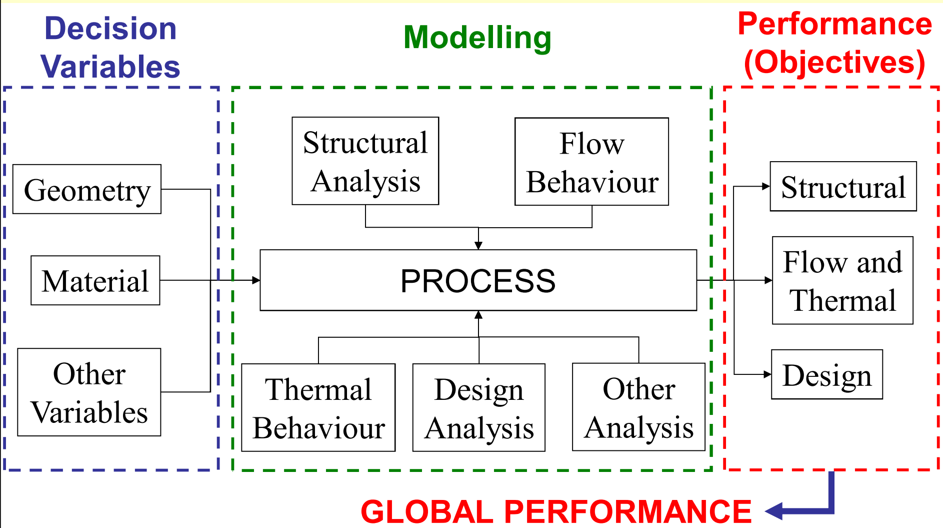
**MODELLING SOFTWARE**

**RESULTS:**
- Output
- Power consumption
- Melt temperature
- Temperature homogeneity
- Degree of Mixing
- Length required for melting
- Pressure generation
- ...



## *optimization methods*

Complicated mathematical models are able to describe adequately the (Engineering) processes to be optimized



## optimization methods

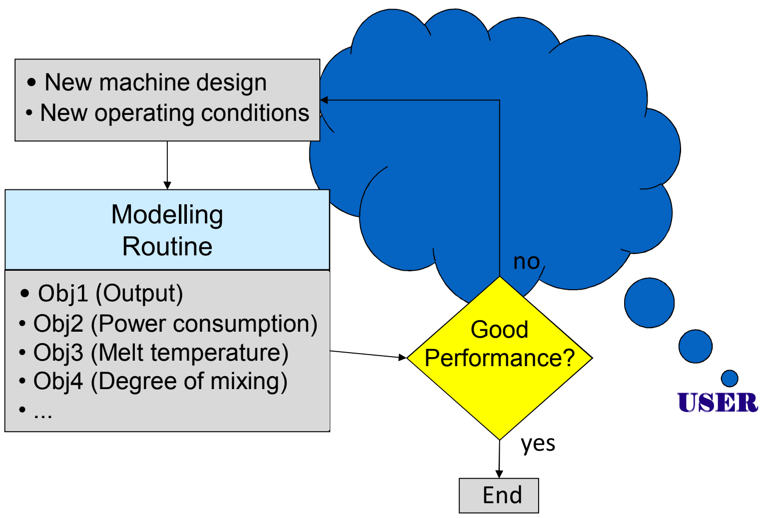
***Approaches to optimize the processes (e.g., set the operating conditions, design machines, etc…):***

- **Use empirical knowledge;**
- **Use computational tools on a trial and error basis;**
- **Solve the inverse problem;**
- **Perform a partial process optimization;**
- **Develop a global optimization procedure.**



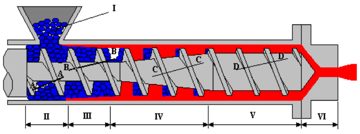
## optimization methods

**Use computational tools on a trial and error basis**



## *optimization methods*

### Solve the inverse problem



***Direct problem*:**

- Geometry
- Material properties
- Operating conditions

Governing equations →

- Output
- Power consumption
- Melt temperature
- Degree of mixing
- ...

***Inverse problem*:**

- Material properties
- Output
- Power consumption
- Melt temperature
- Degree of mixing
- ...

Governing equations →

- Geometry
- Operating conditions
- ...

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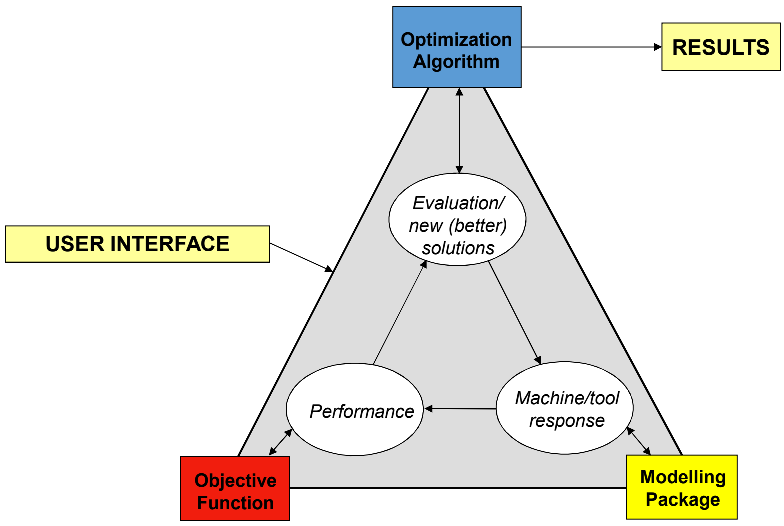
## *optimization methods*

### Develop a global optimization procedure

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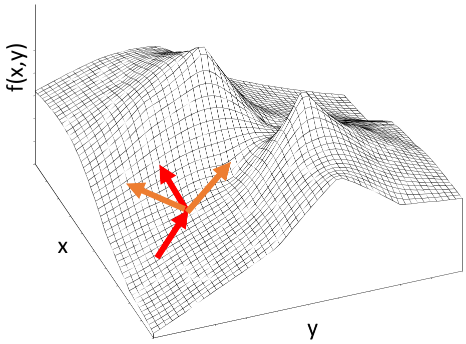
## optimization methods

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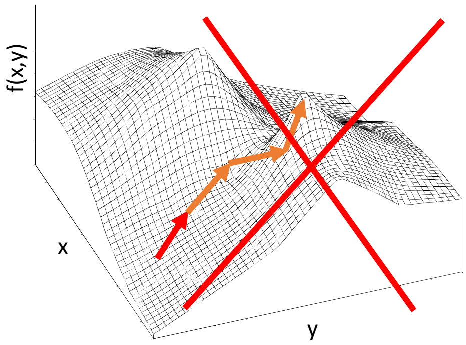
## optimization methods

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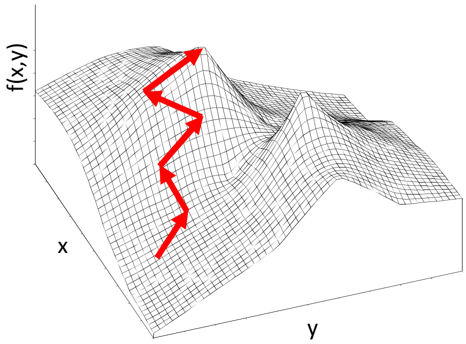
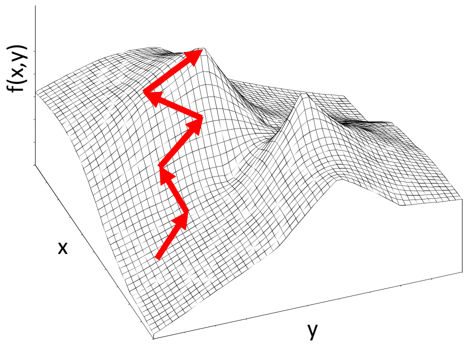
## optimization methods





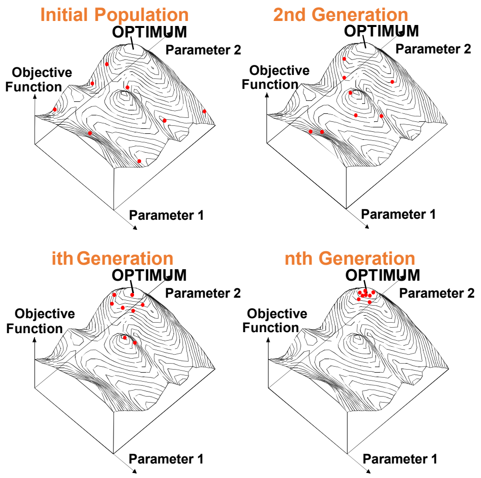

## optimization methods




OPTIMIZATION ALGORITHMS

- Random search
- Gradient methods
- Simulated annealing
- Neural networks
- Expert systems
- Sensitivity analysis
- Statistical methods
- Ant colony optimization
- Evolutionary algorithms

## *evolutionary algorithms*




- **Search uses a population of points**
- **Able to distinguish between local and absolute maxima**
- **Do not require derivatives nor other knowledge on the process (BLACK BOX)**
- **Require significant computation resources**



## *evolutionary algorithms*

The role of optimisation is to find the best set of parameters that optimise an objective function, particularly by improving the performance in the direction of some optimal point or points:

$$\begin{array}{lll} \text{maximise}_{x\in\Omega} & f(x_i) & i=1,\ldots,n \\ \text{subject to} & g_j(x_i)\geq 0 & j=1,\ldots,J \\ & h_k(x_i)=0 & k=1,\ldots,K \end{array}$$

where $x$ is a vector of $n$ and $\Omega \subset \Re^n \left(\Omega = \{x \in \Re^n : l \leq x \leq u\}\right)$

***f*** **is the objective function of the** ***n*** **parameters** $x_i$, $g_j$ **are the** ***J*** **(*J*≥0) inequality constraints, and** ***k*** **are the** ***K*** **(*K*≥0) equality constraints.**

*evolutionary algorithms*

- Evolutionary Algorithms (*EAs*) are stochastic search and optimisation methods that mimic natural evolution through genetic operators like crossover and mutation.
- They work with a population of points, each one representing a possible solution in the search space.
- Each individual has a value associated to it (fitness or objective function), which is a measure of its performance on the system.
- Individuals with greater performance have a bigger opportunity for reproduction, i.e. to pass their characteristics to future.



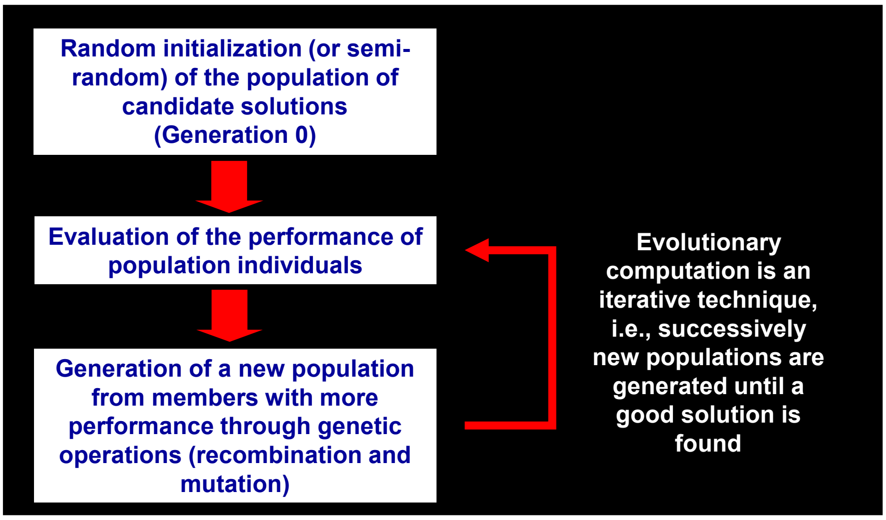
*evolutionary algorithms*

## Evolutionary Computation – THE METAPHOR

| Natural Evolution | | Evolutionary Computation |
|---|---|---|
| Individual | ↔ | Solution |
| Performance | ↔ | Quality |
| Environment | ↔ | Problem |

*evolutionary algorithms*

## The Computational Cycle

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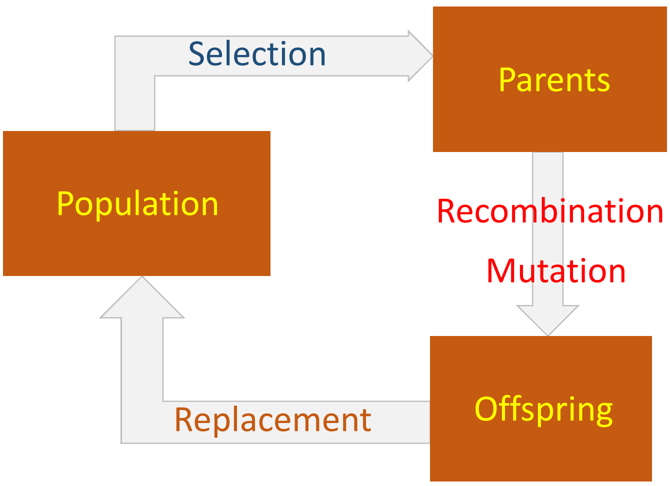
*evolutionary algorithms*

## The Evolutionary Cycle

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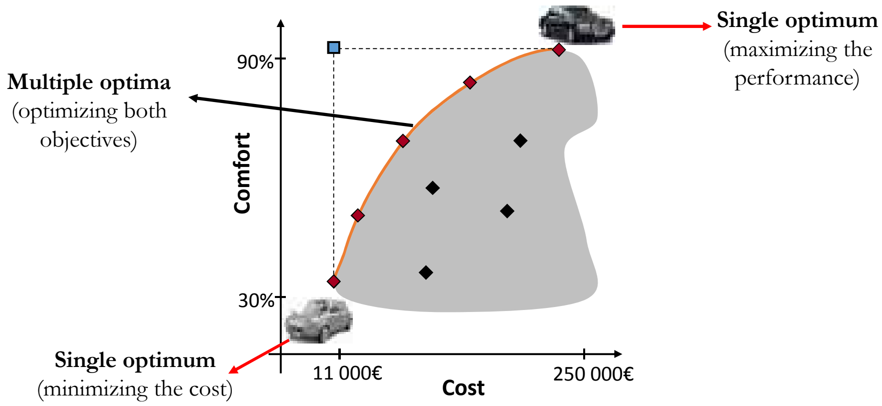
*multi-objective evolutionary algorithms*

## Most real optimization problems are multi-objective

**Example**: Simultaneous minimization of the cost and maximization of the performance (comfort) when buying a car

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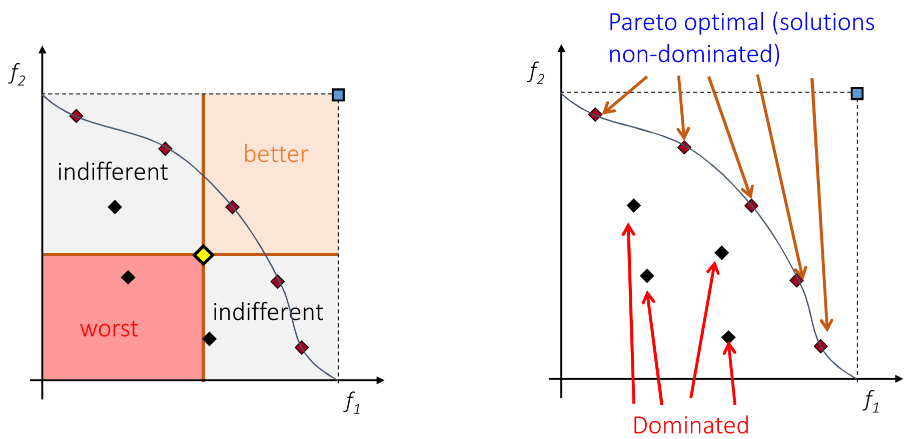
## Non-Dominance Concept

$$\text{maximize} \quad f_1(x_i), f_2(x_i)$$

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## Multi-Objective Optimization Problem

$$\begin{array}{llll} \min\limits_{x_i} & f_l(x_i) & i=1,\cdots,n & l=1,\cdots,M \\ \text{subject to} & g_j(x_i)=0 & j=1,\cdots,J & \\ & h_k(x_i)\geq 0 & k=1,\cdots,K & \end{array}$$

**where $f_l$ are the $M$ objective functions of the $n$ parameters $x_i$, and $g_j$ and $h_k$ are the $J$ equality ($J\geq0$) and $K$ inequality ($K\geq0$) constraints, respectively**

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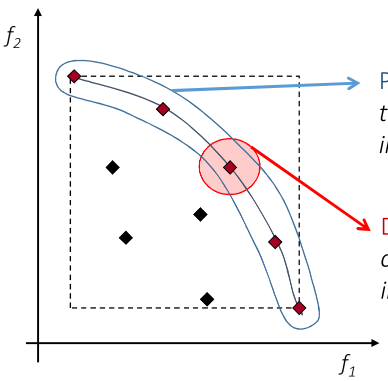
## Decision making




Pareto Optimality (*a set of optimal trade-offs, all objectives have equal importance*)

Decision Making (*choose the best compromise based on preference information*)

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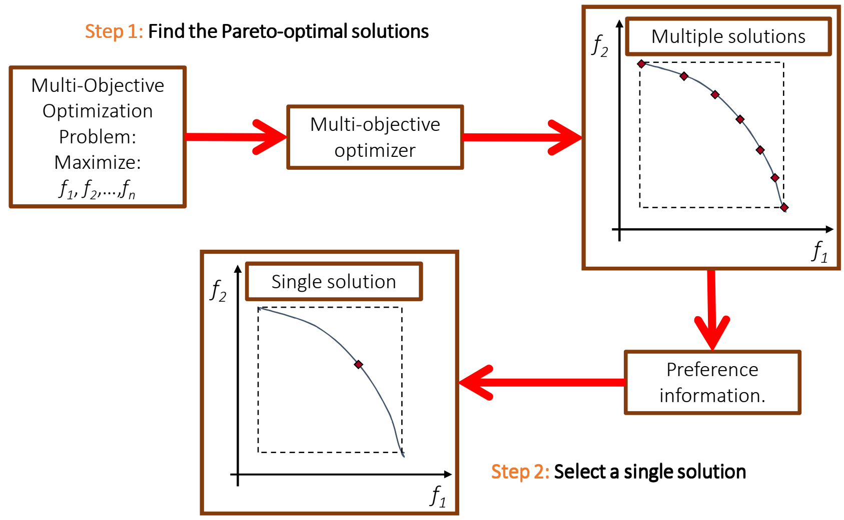
## Multi-Objective Optimization

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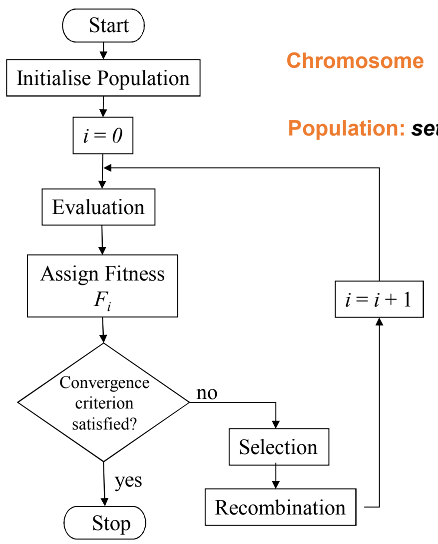
## Evolutionary Algorithm




**Chromosome**

| L1 | | | | L2 | | | | D1 | | | | D3 | | | | e | | | | P | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

**Population:** ***set of chromosomes or individuals***

**Initialization of population:** ***random definition of all individuals of the population***

**Evaluation:** ***calculation of the values of the objectives using the modeling routine***

**Fitness:** ***calculation of a single value identifying the performance of individual***

**Reproduction:** ***selection of the best individuals for crossover and/or mutation***

**Crossover/Mutation:** ***methods to obtain new individuals for the next generation (i+1)***

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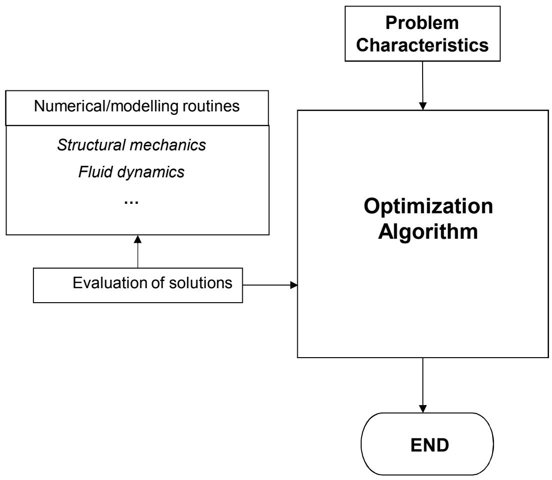
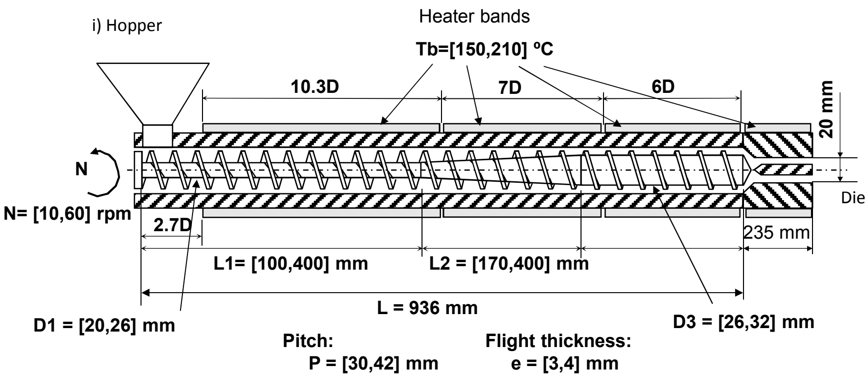
## *multi-objective evolutionary algorithms*

### Optimization Methodology



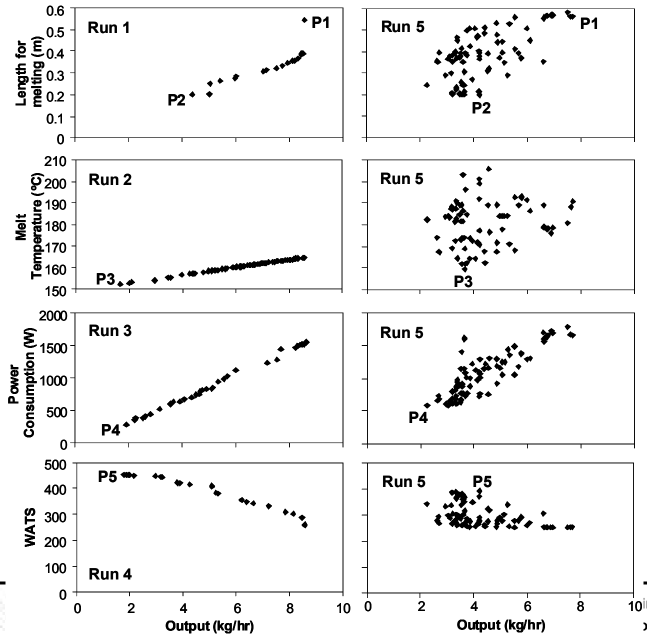



## *results*




| Objectives | Aim | $X_{min}$ | $X_{max}$ |
|---|---|---|---|
| Output – Q (kg/hr) | Maximize | 1 | 20 |
| Length for melting – L (m) | Minimize | 0.2 | 0.9 |
| Melt temperature – T (ºC) | Minimize | 150 | 210 |
| Power consumption – P (W) | Minimize | 0 | 9200 |
| WATS | Maximize | 0 | 1300 |

## *results*






## *WHAT DO WE NEED FROM PREVIOUS STEPS OF THE PROJECT?*

- **Polymer properties**
- **Operating conditions**
- **System geometry**

*WHAT DO WE NEED FROM PREVIOUS STEPS OF THE PROJECT?*

## Polymer properties

- Friction coefficients (very important);
- Solid density = f(P,T);
- Melt density = f(P,T) – PVT;
- Thermal conductivity (solid and melt);
- Heat capacity (solid and melt);
- Heat of fusion;
- Melting temperature;
- Viscosity = f(T, shear rate)



# Thanks!

# Debate

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