Cost evaluation of radiation-cured concrete-polymer materials for pipe manufacture

Singer, Klaus Albert Julius; Vinther, A.; Bjergbakke, Erling; Fördös, Z.; Skytte, M.; Winther, J.

Publication date: 1970

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Cost Evaluation of Radiation-Cured Concrete-Polymer Materials for Pipe Manufacture

by

K. Singer & A. Vinther, Chemistry Department
E. Bjergbakke, Accelerator Department
Danish Atomic Energy Commission
Z. Fördös, Concrete Research Laboratory Karlstrup
M. Skytte, Betonvarefabriken "Sjælland"
J. Winther, Pedershåb Machine Works Ltd.
A conceptual design and preliminary cost evaluation was made for the production of radiation-cured plastic impregnated concrete pipes with internal diameters of 30 and 150 cm respectively and a length of 200 cm.

The calculation of the Co-60 source strength was based on linear absorption of radiation from an infinite rod source using data for mass stopping power and build-up factors as for shielding calculations.

The evaluation was only based upon obtainable increase in strength properties, whereas improvement of corrosion resistance was not especially considered.

Production costs for plastic impregnated concrete pipes with strength properties of the same order as those of steel-reinforced pipes or pipes otherwise "refined" were about 50% higher than for these pipes.

With a growing market need for corrosion-resistant pipes, e.g., for sewage and industrial waste water, it cannot be excluded that even considering the rather high production costs, the use of plastic-impregnated concrete pipes could turn out to be economic.
Contents

1. Introduction p. 1

2. Plant Description for Large Pipes 2
   2.1. Design Premises 2
   2.2. Plant Lay-out 3
   2.3. Design of Radiation Sources 4
       2.3.1. Radiation Dose 4
       2.3.2. Irradiation Geometry 4
       2.3.3. Source Strength 5
       2.3.4. Factors Influencing the Design and the Source Strength 6

3. Plant Description for Small Pipes 8
   3.1. Design Premises 8
   3.2. Plant Lay-out 8
   3.3. Radiation Source Strength 8

4. Initial Investments 9
   4.1. Plant for Large Pipes 9
   4.2. Plant for Small Pipes 10
   4.3. Co-60 Sources 10

5. Production Costs 11

6. Discussion 15

7. Conclusion 17
1. Introduction

Experimental work on radiation-cured concrete-polymer materials has been started as a joint programme by the Concrete Research Laboratory, Karlstrup, and the Danish Atomic Energy Commission, Research Establishment Risö.

Preliminary investigations included a number of material combinations: light-weight concrete, normal-strength concrete and high-strength vibropressed concrete, various hard-compressed cement-sand mortars, sand-lime bricks and plaster of Paris impregnated with methylmethacrylate, styrene/acrylonitrile and unsaturated polyesters. Large increases in compressive strength and splitting tensile strength were obtained. Thus compressive strengths of more than 2000 kg/cm² were reached with a special concrete.

*Presented at the Conference on Radiation and Isotope Techniques in Civil Engineering, Brussels, October 28-29, 1970.*
As a guide to the future research programme it was decided to make a conceptual design and preliminary evaluation study in direct collaboration with Danish Manufacturers of concrete pipes and concrete pipe machines. The purpose of these investigations was to evaluate the possible advantages of introducing plastic impregnation in concrete pipe production.

The polymer impregnation process was considered to be of greatest interest for unreinforced pipes of large dimensions. It was therefore decided to calculate and optimize the production plant for one dimension: a circular pipe with an internal diameter of 160 cm and a length of 200 cm was chosen. The conceptual design for the entire plant was made for this dimension, and the thickness of the concrete pipe was chosen so that maximum efficiency of the radiation source was obtained. This was done in order to find the most promising design for the process.

It is assumed that the final plant could also be used for production of pipes of somewhat smaller dimensions. It was, however, also of interest to make an evaluation of a plant for much smaller pipes with, for instance, an internal diameter of 30 cm and a length of 200 cm. For this evaluation the plant described by Kukaoka, Steinberg and Manowitz (ref. 1) was considered suitable.

2. Plant Description for Large Pipes

2.1. Design Premises

It was found that the concrete in this type of pipes could be impregnated with four weight per cent of polymethyl methacrylate. Experimental results showed that a tensile strength in bending of two hundred kg/cm² could be expected, and this value was used for determination of the relation between wall thickness and supporting strength of the pipes. As a result of an optimisation calculation for the design of the radiation source a wall thickness of 12 cm was chosen. A pipe with this thickness and a total weight of 3,250 kg has the same supporting strength as an unimpregnated and unreinforced pipe with a wall thickness of 20 cm and a weight of 5,600 kg.

2.2. Plant Lay-out

A conceptual design for a facility to produce twenty-four large pipes per day of plastic-impregnated concrete is shown in figure 1. The plant consists of a drying oven, an impregnation tank and twenty-four separate irradiation holes. Furthermore the plant comprises a monomer storage tank, pumps, transporting systems, and a dip tank.

A typical process cycle would be as follows: each concrete pipe is placed on a separate carrier and wheeled into the drying oven which can contain twenty-four pipes at the same time. Eight pipes are taken out for cooling after twenty-four hours of drying and are then taken to the vacuum-impregnation tank. The tank is sealed and evacuated. After a prescribed period of evacuation the tank is charged with monomer from the monomer storage tank, and the pipes are then impregnated so that the total evacuation-impregnation cycle takes eight hours. The monomer is pumped back to the storage tank, and the pipes are taken out one by one, lifted up by a double-rail, overhead travelling crane and dipped in the dip tank containing a viscous solution of polymer in monomer in order to minimize evaporation losses. Finally the pipe is placed on a tray which will take up excess monomer and then in an empty irradiation hole. A concrete shielding plug is then placed over the irradiation hole and the source is raised into irradiation position from the shielded under part below the irradiation hole and is kept there for twenty-four hours of irradiation.

For optimization of the total method it was necessary to estimate the radiation dose.
2.3. Design of Radiation Source

2.3.1. Radiation Dose

On the basis of experimental work it was concluded that the minimum radiation dose required for complete polymerization of methyl methacrylate, impregnated into concrete, would be $2.0 \times 10^5$ rads at a dose rate of $3.5 \times 10^5$ rads/hour. The calculations are furthermore based on the assumption that the minimum curing dose, $D_{\text{min}}$, varies proportionally to the square root of the dose rate, $R$, i.e.

$$D_{\text{min}} = K \sqrt{R}.$$  

On the basis of this equation and on the experimental set of values for $D_{\text{min}}$ and $R$, and furthermore on the fact that $D = R \times T$ (where $T$ is the irradiation time) it is possible to calculate $R$ and $D_{\text{min}}$ for a given $T$.

For an irradiation time of twenty-four hours we find:

$$D_{\text{min}} = 4.75 \times 10^5 \text{ rads}, \quad R = 1.98 \times 10^5 \text{ rads/hour}.$$  

2.3.2. Irradiation Geometry

The absorbed radiation dose decreases with increasing concrete thickness. Figure 2 illustrates the relative absorbed dose as a function of concrete thickness for normal concrete, $\rho = 2.49 \text{ g/cm}^3$. Data for mass stopping power and build-up factor are given in references 2 and 3.

Among the different geometries taken into consideration the single-rod source in the centre of the concrete pipe was found to be the most economic((a) on next page).

A geometry for two-side irradiation (b) requires 20% greater source strength and more complicated source handling equipment: Any geometry including moving sources or moving target gives higher "local" dose rates, and thereby lower utilization of the source.

2.3.3. Source Strength

The basic calculation criterion is that the outer side of the concrete pipe should receive the required minimum radiation dose during the prescribed irradiation time. As the absorbed dose will increase directly proportionally to the dose rate as the distance to the central source decreases right through the pipe wall ($D = R \times T$), whereas the required minimum dose for polymerization will increase only proportionally to the square root of the dose rate ($D_{\text{min}} = K \sqrt{R}$), all other parts of the concrete pipe will absorb more than the required minimum dose, ensuring complete curing of the impregnated monomer.

From the curve in figure 2 it is possible to calculate the average radiation dose absorbed in the concrete pipe when the required minimum dose for the outer part of the pipe is known, and the fraction of transmitted, i.e. lost radiation energy.

For calculation of the total radiation dose necessary and hence of the required source strength, it is more necessary to estimate the radiation at other positions.
at the ends of the pipe and the losses due to selfab-
sorption in the source.

For an irradiation time of twenty-four hours we
find:

- Dmin: $4.75 \times 10^5$ rads
- $R$: $1.98 \times 10^4$ r/hour
- Average dose: $1.07 \times 10^6$ rads
- Average dose rate: $4.85 \times 10^5$ r/hour
- Total absorbed energy per hour: $1.45 \times 10^6$ joules/h
- Loss due to transmission: $0.43 \times 10^6$
- Loss due to selfabsorption estm.: $0.22 \times 10^6$
- Loss at the ends estm.: $0.15 \times 10^6$
- Total radiation energy per hour: $2.25 \times 10^6$ joules/h

Source strength: $2.25 \times 10^6 \times \frac{1}{51.1} \text{ Ci } ^{60}\text{Co}$

$$= 44,000 \text{ Ci } ^{60}\text{Co}.$$  

This is the source strength necessary to irradiate
one concrete pipe a day (twenty-four hours).

For the production of twenty-four concrete pipes a
day the total source strength will be 1,100,000 curies.

It should be noted that the calculations are based
on linear absorption of radiation from an infinite rod
source. The estimate of loss at the ends of the pipe might
be somewhat optimistic.

### 2.3.4. Factors Influencing the Design and the Source
Strength

#### 2.3.4.1. Irradiation Time

The necessary source strength per pipe will decrease
greatly with increasing irradiation time owing to the square
root dependence of the dose on dose rate. On the other hand
an increase of irradiation time will necessitate a corre-
spondingly larger number of radiation sources in order to
maintain the same production capacity.

For reasons of comparison the source strength per pipe,
the number of sources and the total source strength required
for irradiation of twenty-four large concrete pipes a day
are listed below for three different irradiation times:

<table>
<thead>
<tr>
<th>Irradiation time</th>
<th>Source strength per pipe</th>
<th>Number of $^{60}$Co sources</th>
<th>Total source strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 h</td>
<td>400,000</td>
<td>8</td>
<td>3,200,000</td>
</tr>
<tr>
<td>24 h</td>
<td>44,000</td>
<td>24</td>
<td>1,100,000</td>
</tr>
<tr>
<td>48 h</td>
<td>11,000</td>
<td>48</td>
<td>530,000</td>
</tr>
</tbody>
</table>

Depending on the costs of $^{60}$Co and unit costs of irradiation
facilities as well as on other building costs the above-
mentioned mutual dependence may strongly influence the final
design of a production plant.

#### 2.3.4.2. Wall Thickness of Concrete Pipe

According to the curve in figure 2 the energy losses
by transmission and the effective utilization of the absorbed
radiation dose will depend on the wall thickness of the
concrete pipe.

Rough calculations show that for wall thicknesses of
more than approximately twenty cm the average dose absorbed
(and hence the source strength) will increase so much that
irradiation from two sides must be considered. On the other hand
at thicknesses below approximately eight cm the energy
transmission will be so great that simultaneous irradiation
of more than one wall thickness of concrete pipe should be
considered. This is in good agreement with the design of a $^{60}$Co
irradiation facility reported in reference 1, where a
irradiation of 9.6 cm (3.75 inch) thick concrete pipe was
in design. A total of 30,000 Ci of $^{60}$Co sources were used,

*Note:* The rest of the text is not fully legible due to the quality of the image, but it seems to continue discussing the design and the source strength, including factors influencing the design, irradiation time, and wall thickness of concrete pipes.
3. Plant Description for Small Pipes

3.1. Design Premises

The pipe chosen for this evaluation has the following dimensions: 30 cm i.d. x 200 cm length x 3.8 cm wall thickness. Assuming, as for the large pipes, an impregnation with four weight per cent of methyl methacrylate and a flexural strength of 200 kg/cm² of the treated concrete, this pipe with a total weight of 205 kg has the same supporting strength as an unimpregnated and unreinforced pipe with a thickness of 6.7 cm and a weight of 390 kg.

3.2. Plant Lay-out

The conceptual design for a facility producing one hundred and sixty-eight pipes a day with the following dimensions: 30 cm internal diameter, 200 cm length and a wall thickness of 3.8 cm, was chosen in accordance with that described in reference 1. The design in this investigation implies the simultaneous irradiation of a number of pipes resulting in irradiation through four times the wall thickness, a total of about fifteen cm of concrete (see figures 3 and 4).

3.3. Radiation Source Strength

In agreement with the principles of calculation outlined in 2.3.3, we find for the irradiation of fifty-six pipes in eight hours (168 pipes a day) with a source geometry as described in ref. 2:

\[
\begin{align*}
\text{Dmin} & = 1.4 \times 10^6 \text{ rads} \\
K & = 1.75 \times 10^6 \text{ rads/hour} \\
\text{Average dose} & = 4.2 \times 10^6 \text{ rads} \\
\text{Average dose rate} & = 5.75 \times 10^5 \text{ rads/hour} \\
\text{Total absorbed energy per hour} & = 4.98 \times 10^7 \text{ joules/hour} \\
\text{Loss due to transmission, estm.} & = 1.48 \times 10^7 \\
\text{Loss due to scattering, estm.} & = 0.74 \times 10^7
\end{align*}
\]

Loss at the ends, estm. .......... 0.50 \times 10^7 \text{ joules/hour}
Total radiation energy per hour ...... 7.66 \times 10^7 \text{ joules/hour}
Source strength: 7.66 \times 10^7 \times \frac{1}{55.1} \text{ Ci }^{60}\text{Co}
\Rightarrow 1.5 \times 10^6 \text{ Ci }^{60}\text{Co.}

4. Initial Investments

4.1. Plant for Large Pipes

The plant costs have been estimated on the basis of separate cost evaluations for the different pieces of equipment necessary for the manufacture: drying oven, evacuation/impregnation tank, dip tank, monomer storage tank, twenty-four irradiation holes, pumps, transporting systems, and building costs. The total facility costs for this plant, which do not include the Co-60 costs and the source moving mechanism, are estimated to be as follows:

\[
\begin{align*}
\text{Irradiation holes} & = \text{kr. } 240,000 \\
\text{Buildings (1250 m}^2 \text{ high building + 800 m}^2 \text{ low building)} & = \text{kr. } 1,500,000 \\
\text{Drying oven} & = \text{kr. } 500,000 \\
\text{Evacuation/impregnation tank} & = \text{kr. } 400,000 \\
\text{Monomer tank and pumps etc.} & = \text{kr. } 240,000 \\
\text{Transporting systems:} & \\
\text{Crane} & = \text{kr. } 185,000 \\
\text{Trolleys} & = 70,000 \\
\text{48 wheeled} & = 415,000 \\
\text{Carriers} & = \text{kr. } 70,000 \\
\text{Tails etc.} & = 70,000 \\
\text{Facility cost} & = \text{kr. } 2,400,000
\end{align*}
\]
4.2. Plant for Small Pipes

In their study Kukacka et al. (ref. 1) have estimated the facility costs for a plant with a throughput of approximately 580 pieces/day, in four-hour shifts - corresponding to approx. 98 pipes per cycle - with a length of 3 ft (approx. 100 cm) to be in the range of $400,000 and $480,000 for radiation source strengths of 3.75 and 4.65 x 10^5 Ci Co-60 respectively. Their evaluation is based on the assumption of a radiation dose for total cure of 0.5 Krad.

The present study involves a considerably higher radiation dose for total polymerization of the impregnated monomer and hence a larger radiation source, which demands more shielding. The prescribed production capacity of 168 pipes per day, in eight-hour shifts, and with a length of 200 cm, corresponding to 56 pipes per cycle, requires a plant of approximately the same dimensions as the one described in the above-mentioned report. For this plant the costs have been estimated to be as follows based on local conditions:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost (kr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth shielding and concrete doors</td>
<td>50,000</td>
</tr>
<tr>
<td>Buildings (covering the drying oven and trolley rails)</td>
<td>500,000</td>
</tr>
<tr>
<td>Drying oven</td>
<td>300,000</td>
</tr>
<tr>
<td>Two impregnation/irradiation tanks</td>
<td>500,000</td>
</tr>
<tr>
<td>Transporting systems:</td>
<td></td>
</tr>
<tr>
<td>Wheeled carriers</td>
<td>280,000</td>
</tr>
<tr>
<td>Two trolleys</td>
<td>70,000</td>
</tr>
<tr>
<td>Rails etc.</td>
<td>80,000</td>
</tr>
<tr>
<td>Monomer tank + pumps</td>
<td>200,000</td>
</tr>
<tr>
<td>Facility cost</td>
<td>1,980,000</td>
</tr>
</tbody>
</table>

5. Production Costs

An effective working year of 300 days has been assumed, corresponding to a plant utilization factor of approximately 84%.

Monomer: A 4.7 weight-% impregnation with methyl methacrylate has been used for these calculations, as mentioned in 2.1. To this figure 10% are added to cover handling losses. A cost of 3.00 kr/kg for methyl methacrylate has been used.

Co-60 replacement: For the source strength to be maintained at approximately the initial level, 13% of the initial loading must be replaced every year. The cost of this replacement Co-60 has been assumed equal to the initial investment cost, 2.00 and 4.00 kr/Ci.

Utilities: These costs include heating for the drying of the pipes prior to impregnation, electricity for pumps and cranes, water, etc. Drying costs are estimated at 12 kr per large pipe, or 87,000 kr/year, electricity consumption at 2500 kwh/day, or 100,000 kr/year, and water etc. at about 13,000 kr/year, in all 200,000 kr/year, corresponding to approx. 5.5% of the facility costs.

Operating labour costs: Labour costs are based on 4 1/3 shift per week, each consisting of two workers and one operator at 50,000 kr/year/man. Furthermore are added costs for 1/3 supervising engineer, i.e. 50,000 kr/year.

Health physics control: This comprises the processing of personnel and plant radiation monitors, periodic physical examinations and radiation surveys. A cost of 70,000 kr is assumed.

Maintenance and supplies: These costs are estimated at 10% of the facility cost (excluding source replacement).
Depreciation and interest of facility: A 10 years' depreciation for buildings and 5 years for equipment has been used at 12% interest.

Depreciation and interest of Co-60 source: A total of 15%/year has been assumed.

Production Cost for Large Pipes

Pipe size: 160 cm (64 inch) internal diameter x 200 cm (80 inch) length x 10 cm (4.8 inch) wall thickness.

Production capacity: 24 pipes/day for 300 days/year: 7,200 pipes/year.

Irradiation time: 24 hours.

<table>
<thead>
<tr>
<th>Co-60 cost</th>
<th>2 kr/Ci</th>
<th>4 kr/Ci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source strength</td>
<td>1.1 x 10^6 Ci</td>
<td>1.1 x 10^6 Ci</td>
</tr>
<tr>
<td>Source cost</td>
<td>2.2 x 10^6 kr</td>
<td>4.4 x 10^6 kr</td>
</tr>
<tr>
<td>Facility cost</td>
<td>3.6 x 10^6 kr</td>
<td>3.6 x 10^6 kr</td>
</tr>
<tr>
<td>Total investment costs</td>
<td>5.8 x 10^6 kr</td>
<td>8.0 x 10^6 kr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production cost</th>
<th>10^6 kr/yr kr/pipe</th>
<th>10^6 kr/yr kr/pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl methacrylate</td>
<td>3.20 416 53.3</td>
<td>3.10 416 48.0</td>
</tr>
<tr>
<td>Co-60 replacement</td>
<td>0.20 28 3.6</td>
<td>0.20 28 3.2</td>
</tr>
<tr>
<td>Operating labour cost</td>
<td>0.70 97 12.4</td>
<td>0.70 97 11.1</td>
</tr>
<tr>
<td>Health physics control</td>
<td>0.07 10 1.3</td>
<td>0.07 10 1.2</td>
</tr>
<tr>
<td>Maintenance and supplies, 8% of facility cost</td>
<td>0.29 40 5.1</td>
<td>0.29 40 4.8</td>
</tr>
<tr>
<td>Depreciation and interest, facility</td>
<td>0.76 105 13.4</td>
<td>0.76 106 14.2</td>
</tr>
<tr>
<td>Depreciation and interest, Co-60 source</td>
<td>0.33 46 5.9</td>
<td>0.66 106 14.1</td>
</tr>
<tr>
<td>Total production cost</td>
<td>5.78 784 100.0</td>
<td>8.46 780 100.0</td>
</tr>
</tbody>
</table>
Production Cost for Small Pipes

Pipe size: 30 cm (12 inch) i.d. x 200 cm (80 inch) length x 3.8 cm (1 inch) wall thickness.
Production capacity: 168 pipes/day in 8 hour shifts of 56 pipes for 300 days/year: 50,200 pipes/year.
Irradiation time: 8 hours.

<table>
<thead>
<tr>
<th>Co-60 cost</th>
<th>2 kr/Ci</th>
<th>4 kr/Ci</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source strength</td>
<td>$1.5 \times 10^6$ Ci</td>
<td>$1.5 \times 10^6$ Ci</td>
</tr>
<tr>
<td>Source cost</td>
<td>$3.0 \times 10^6$ kr</td>
<td>$5.0 \times 10^6$ kr</td>
</tr>
<tr>
<td>Facility cost</td>
<td>$2.0 \times 10^6$ kr</td>
<td>$2.0 \times 10^6$ kr</td>
</tr>
<tr>
<td>Total investment cost</td>
<td>$5.0 \times 10^6$ kr</td>
<td>$8.0 \times 10^6$ kr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production cost</th>
<th>$10^6$ kr/yr</th>
<th>kr/pipe %</th>
<th>$10^6$ kr/yr</th>
<th>kr/pipe %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl methacrylate at 3.00 kr/kg</td>
<td>1.37</td>
<td>27</td>
<td>37</td>
<td>1.37</td>
</tr>
<tr>
<td>Co-60 replacement 139/yr</td>
<td>0.39</td>
<td>8</td>
<td>11</td>
<td>0.78</td>
</tr>
<tr>
<td>Utilities, 5.5% of facility cost</td>
<td>0.11</td>
<td>2</td>
<td>3</td>
<td>0.11</td>
</tr>
<tr>
<td>Operating labour cost</td>
<td>0.70</td>
<td>14</td>
<td>19</td>
<td>0.70</td>
</tr>
<tr>
<td>Health physics control</td>
<td>0.07</td>
<td>1</td>
<td>1</td>
<td>0.07</td>
</tr>
<tr>
<td>Maintenance and supplies, 8% of facility cost</td>
<td>0.16</td>
<td>3</td>
<td>4</td>
<td>0.16</td>
</tr>
<tr>
<td>Depreciation and interest, facility</td>
<td>0.47</td>
<td>9</td>
<td>12.5</td>
<td>0.47</td>
</tr>
<tr>
<td>Depreciation and interest, Co-60 source 139/yr</td>
<td>0.46</td>
<td>9</td>
<td>12.5</td>
<td>0.90</td>
</tr>
<tr>
<td>Total annual production cost</td>
<td>3.72</td>
<td>73</td>
<td>100</td>
<td>4.56</td>
</tr>
<tr>
<td>Additional cost for polymerization of cookepips</td>
<td>73 kr/pipe</td>
<td>200 kr/pipe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Discussion

The evaluations in this report are very sensitive to a number of assumptions, such as the required radiation dose and the monomer content, and to some production parameters, such as plant utilization factor, irradiation time, cobalt-60 price, and production capacity.

The radiation dose required for complete polymerization and used in these calculations was based on experimental work. However, the possibility could not be excluded that on the basis of further research this dose could be reduced essentially, and consequently the cobalt-60 source strength could be reduced in the same proportion. A reduction of the radiation dose by a factor of for instance two would reduce the production costs for a large pipe, depending on the cobalt-60 price, by approximately 5 to 10%.

As it has been clearly demonstrated in the calculations, the monomer costs absolutely dominate the final costs. Therefore any reduction of the free-pore volume during the production process and consequently a reduction in monomer content - with unchanged strength properties of the final product - will be of special importance for the production costs.

The plant utilization has been assumed to be 300 days per year. Owing to the great fraction of the total costs which arises from the monomer costs, an increase in plant utilization to 330 days (10%) will only reduce the production cost per large pipe by approximately 3 to 4%.

As briefly mentioned in 2.3.4.1 the production costs will depend on the relationship between irradiation time, Co-60 source strength and Co-60 price. The following examples will illustrate this dependence. With the production capacity constant, an increase in irradiation time from 24 to 48 hours will reduce the total Co-60 source strength, but will result in a doubling of the number of irradiation hours. For a cost of 3 kr/Ci the increase in facility cost will equalize the increase in source cost. For the higher price however, the total increase becomes 1 kr (1%), and the production cost per pipe...
reduced by 6%.

Similar calculations for a reduction of the irradiation time to 8 hours show that the increase in Co-60 source cost is so high that in order to equal the reductions in building costs etc. a considerable reduction in cobalt price below 2 kr/Ci would be necessary.

A doubling of the production capacity to 48 pipes per day, with the irradiation time constant at 24 hours, will, owing to an estimated reduction in facility and operating labour costs result in a reduction of the production cost per large pipe of approximately 8%.

The purpose of this report has been to carry out a preliminary evaluation of radiation curing of concrete polymer material. As may be well known, an alternative method to the radiation curing is conventional thermo-chemical curing, initiated by chemical catalysts such as organic peroxides.

Without going into detail concerning the lay-out of a plant based on thermal curing it could be said that such a plant would still comprise the same facilities for drying and impregnation as described in this report. A rough estimate indicates that the costs of the chemical catalyst including facilities for heating the concrete pipes to approximately 80°C should be compared with the costs of the Co60 source.

Experimental data show that the amount of catalyst should be at least 2% of the methylmethacrylate weight, and as the price of benzoyl peroxide is approximately 75 kr/kg, or 25 times that of methylmethacrylate, this would mean an additional treatment cost of approximately 200 kr/large pipe. This figure corresponds to the costs arising from the use of the Co60 source in the case of the lowest attainable additional cost. Using these figures, the total production costs of such plastic impregnated concrete pipes with strength properties of the same order as those of steel-reinforced pipes or pipes otherwise "refined", will in both cases be about three times higher than the costs of the corresponding unreinforced and untreated standard pipes.

As we find the same relative increase in production costs in both cases, we believe that on the basis of the principles of calculation presented in this paper, which have led to the design of suitable production plants for rather large and rather small pipes, it should be possible on the basis of further investigations, to design an optimal plant lay-out for other pipe dimensions or combinations thereof with a corresponding increase in production costs.

Under Danish economic conditions the improved strength properties of the concrete would allow an increase in production costs as compared with those for ordinary, untreated pipes, corresponding to a factor of about two.

The present evaluation was, however, only based upon an obtainable increase in strength properties, whereas an expected improvement of other properties, such as durability, fire resistance and resistance to chemical attack was not specifically considered.
With a growing market need for corrosion-resistant pipes, e.g. for sewage and industrial waste water, it cannot be excluded that even considering the rather high production costs, the use of plastic-impregnated concrete pipes might become of interest also from an economic point of view in the years to come.

References


Figure 1. Plant lay-cut for impregnation of large concrete pipes.

Sectional elevation of irradiation hole (dimensions in cm)
Figure 2. Relative absorbed radiation dose vs. thickness of concrete, $\rho = 2.40 \text{ g/cm}^3$. 

- Relative absorbed dose
- Thickness cm

Data points are not visible in the image. The curve shows a decrease in relative absorbed dose with increasing thickness.
Figure 3. Impregnation and irradiation facility for small concrete pipes (from reference 1).
Figure 4. Plant lay-out for impregnation of small concrete pipes.